African easterly waves: Diagnostics and operational model intercomparison.

Gareth Berry and Chris Thorncroft.

University at Albany, State University of New York, Albany, NY, USA.

Anna Agusti-Panareda[1], Julian Heming[2], Jean-Philippe Lafore[3] and Wassila Thiaw[4].

[1] European Centre for Medium Range Weather Forecasts, Reading, Berks, UK.
[2] Met Office, Exeter, UK.
[3] Meteo France, Toulouse, France.
[4] National Centers for Environmental Prediction, Camp Springs, MD, USA.

Contact: gareth@atmos.albany.edu

Overview.

Diagnostics.

• Background.

• Development of an objective method of examining African Easterly Wave (AEW) activity.

Application of diagnostics.

• Using new methods and techniques to compare AEW representation in operational model analyses and forecasts.

Diagnostics – Background and rationale.

• AEWs are the dominant synoptic weather systems that exist over West Africa and the tropical Atlantic during boreal summer.

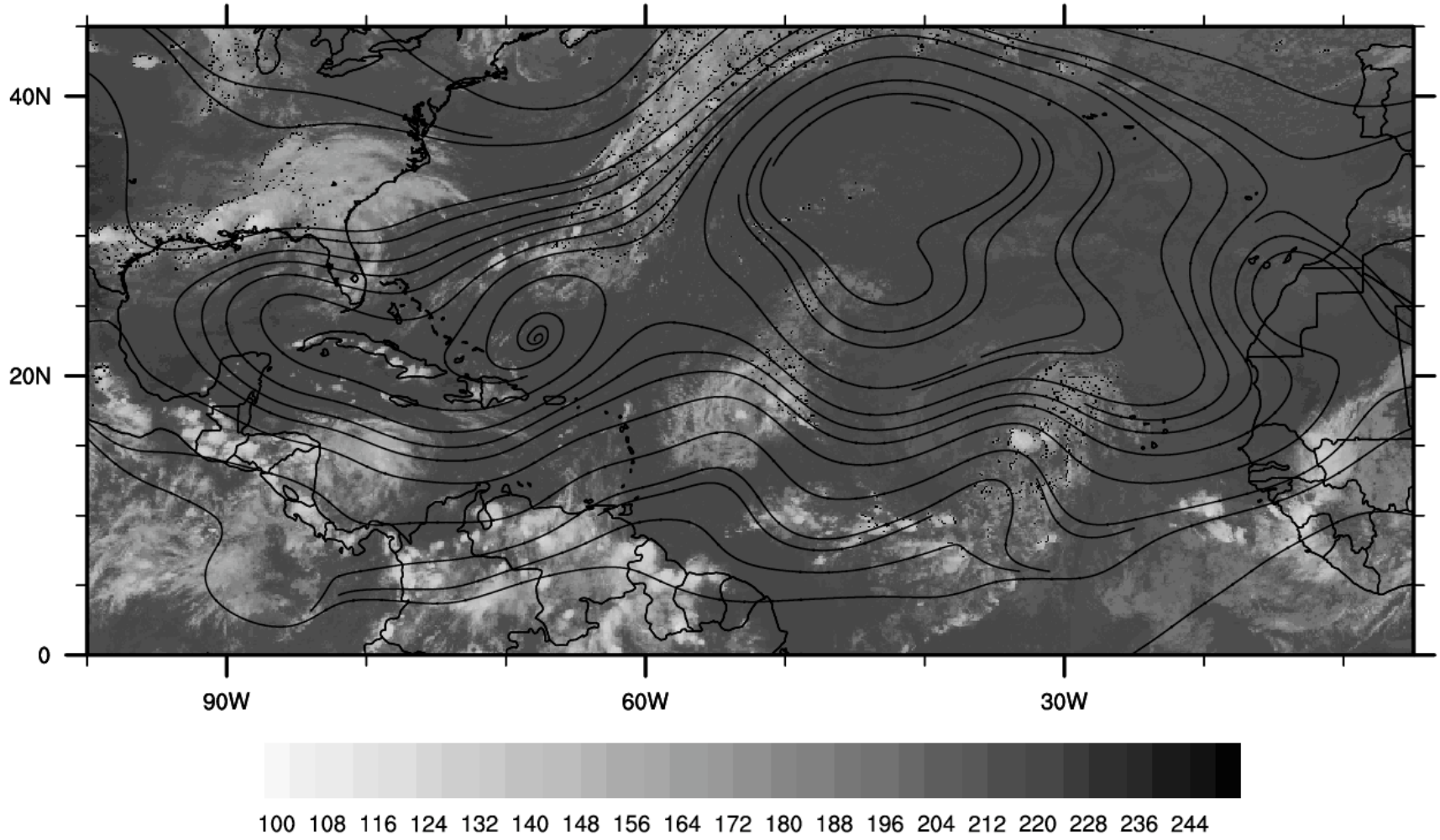
• They are generated over central and eastern Africa and move westward through the West African Monsoon into the tropical North Atlantic and can reach the eastern Pacific basin.

• They are important as they strongly impact precipitation over the African continent and are the main precursors of Atlantic and Eastern Pacific tropical cyclones.

• Their dynamics are believed to be governed by both deep moist convection and ‘more conventional’ synoptic dynamics – this makes tracking and forecasting problematic.

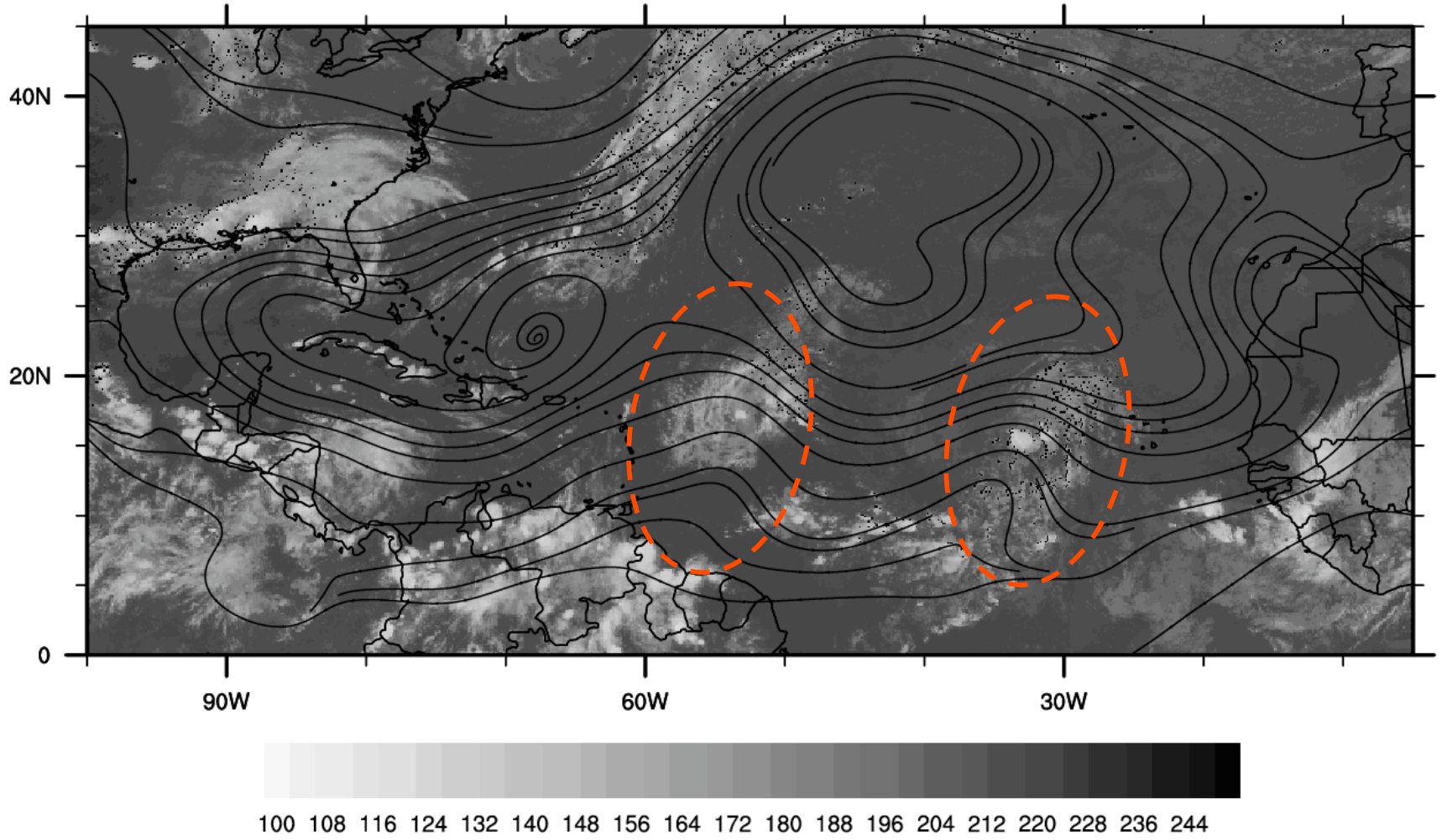
Diagnostics – Background and rationale.

IR and 700hPa streamlines 00UTC Aug 13th 2008 from the GFS analysis:



Diagnostics – Background and rationale.

IR and 700hPa streamlines 00UTC Aug 13th 2008 from the GFS analysis:



Diagnostics – Background and rationale.

• Tendency to use synoptic scale westward propagating cloud clusters in satellite imagery and/or a change in sign of the mid-tropospheric meridional wind (i.e. $v=0ms^{-1}$) to identify AEWs. Can this always be justified? - the dynamical relationship between convection, $v=0ms^{-1}$ and AEWs neither simple or clear.

• Other methods track using absolute vorticity, but this can be messy!

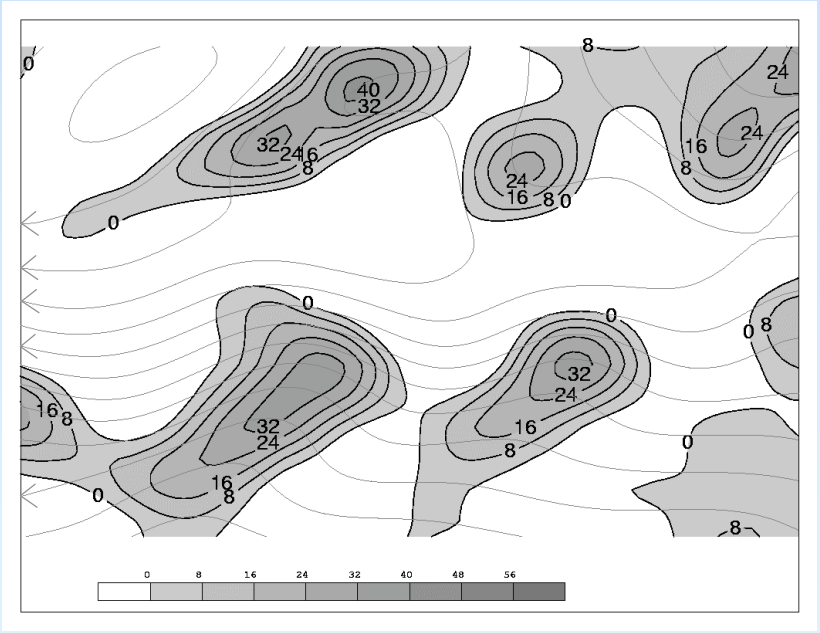
• A lack of consistency may lead to significant differences between analysts, which could have an impact on both end users and forecast verification.

• All the above methods are time consuming – become unfeasible to apply these methods in large amounts of data (e.g. NWP ensemble output).

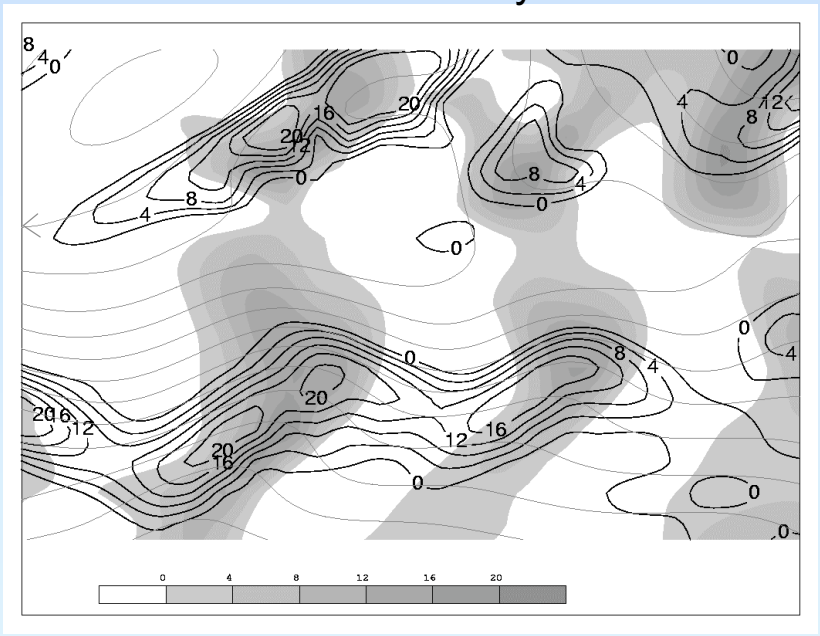
Diagnostics - Basics.

Following Berry, Thorncroft and Hewson (2006) we are using curvature and shear vorticity at 700hPa as the primary diagnostics. As this partitioning helps to isolate AEWs:

Streamlines with Relative vorticity:



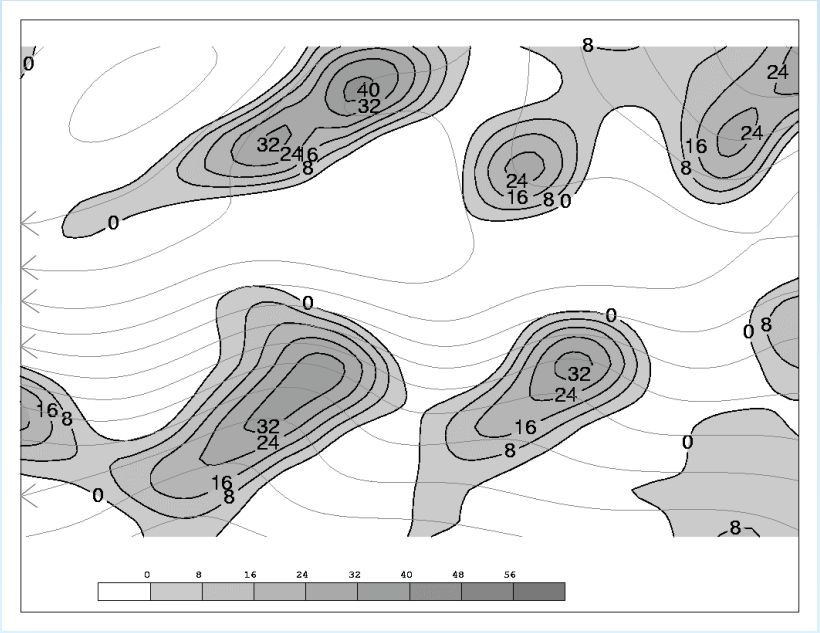
Streamlines with Curvature (shaded) and shear vorticity:



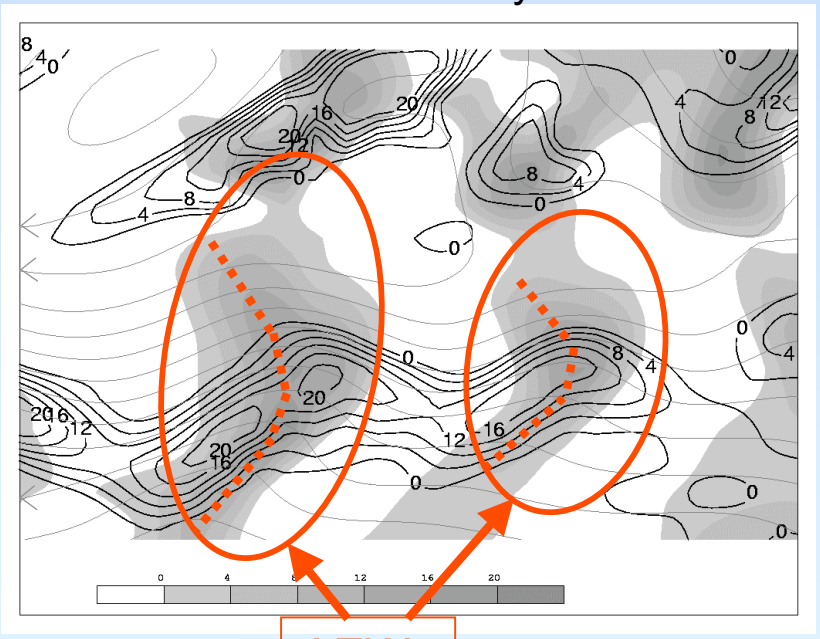
Diagnostics - Basics.

Following Berry, Thorncroft and Hewson (2006) we are using curvature and shear vorticity at 700hPa as the primary diagnostics. As this partitioning helps to isolate AEWs:

Streamlines with Relative vorticity:



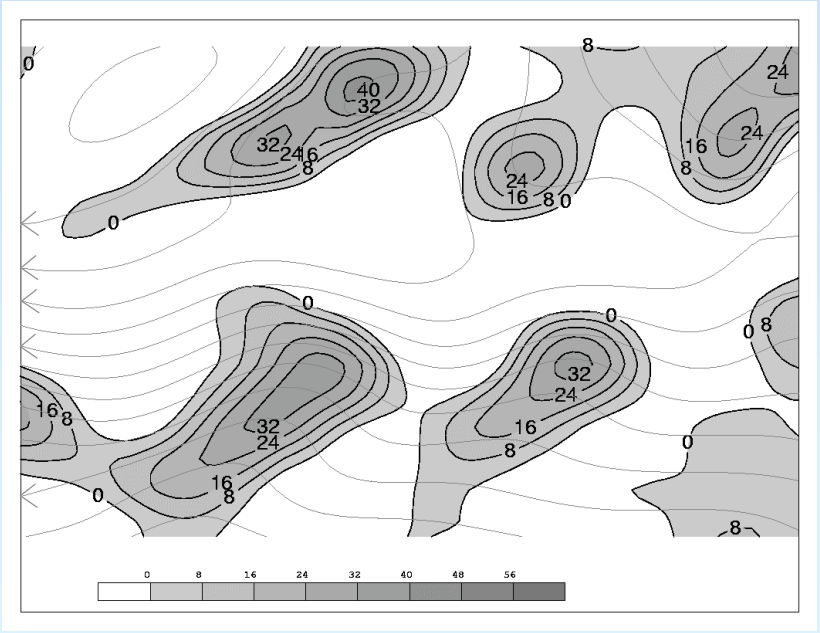
Streamlines with Curvature (shaded) and shear vorticity:



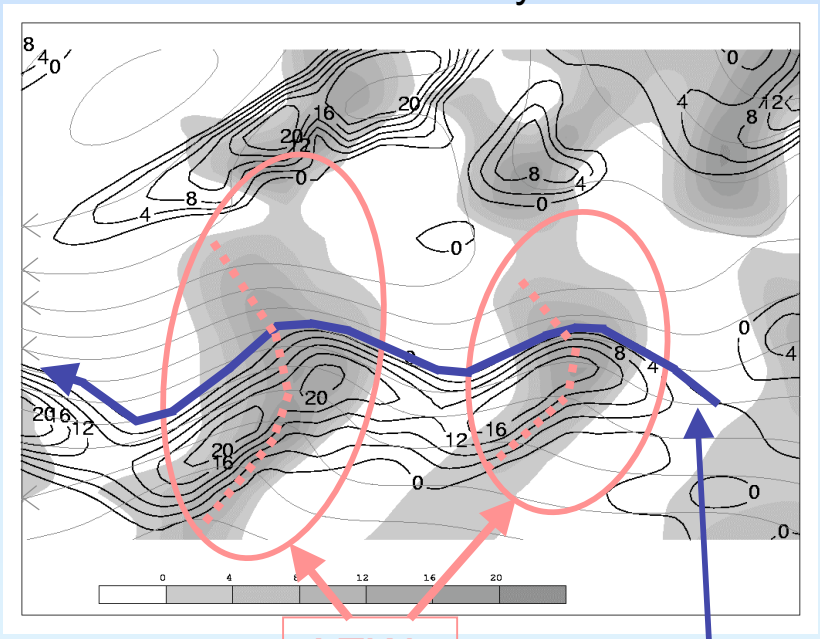
Diagnostics - Basics.

Following Berry, Thorncroft and Hewson (2006) we are using curvature and shear vorticity at 700hPa as the primary diagnostics. As this partitioning helps to isolate AEWs:

Streamlines with Relative vorticity:

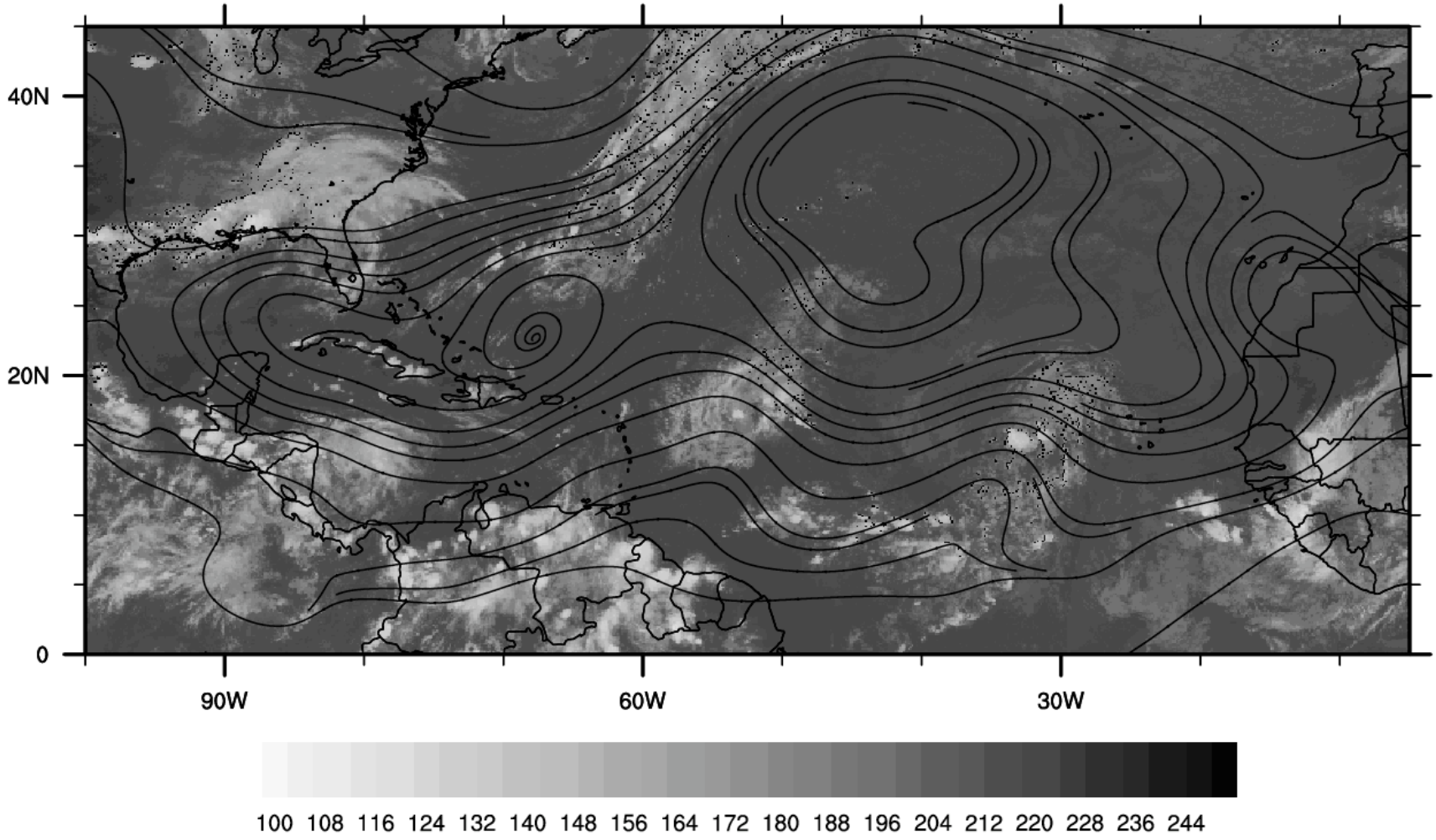


Streamlines with Curvature (shaded) and shear vorticity:



Diagnostics - Example.

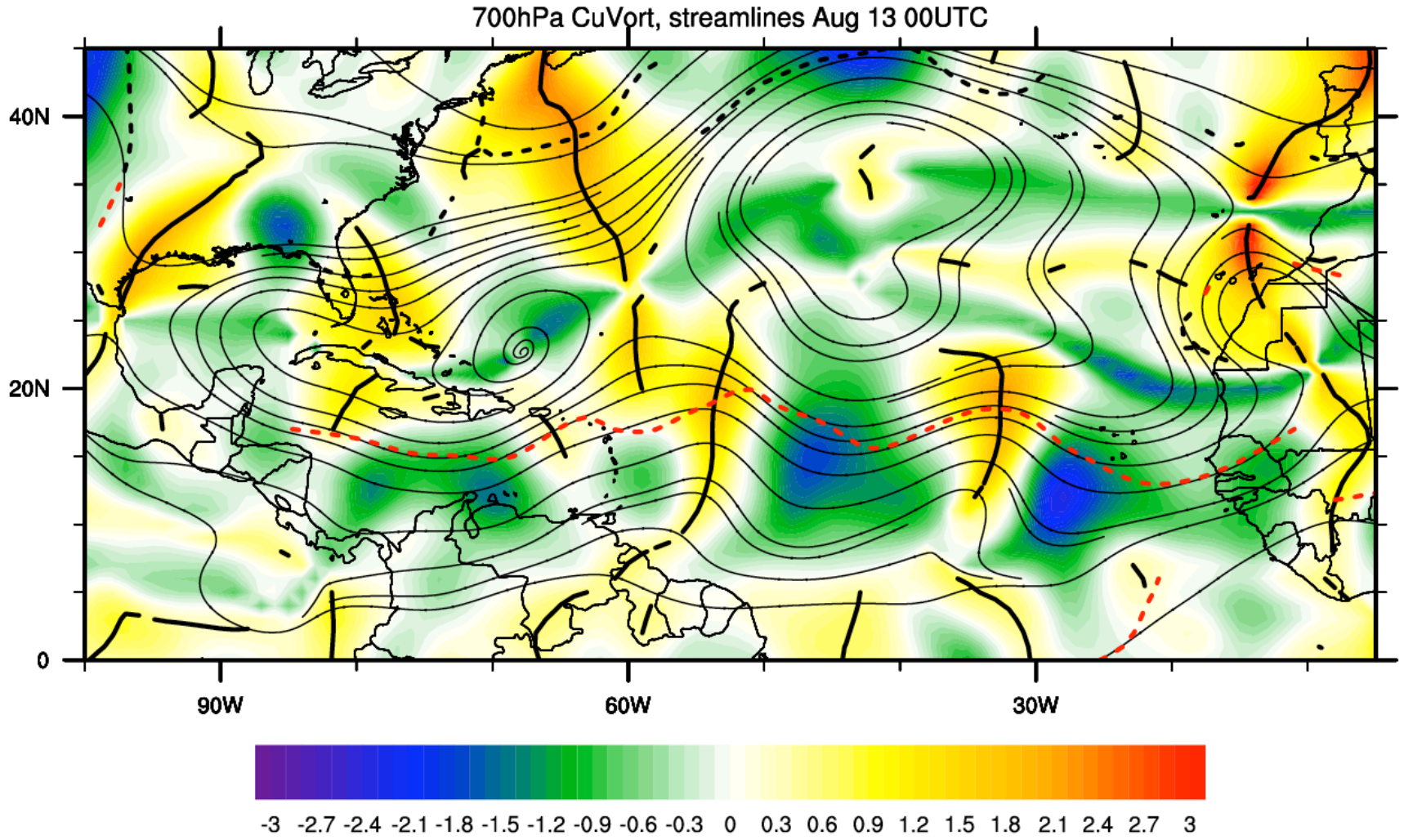
Example of the diagnostics (Aug 13th 2008) using GFS analysis:



IR and 700hPa streamlines.

Diagnostics - Example.

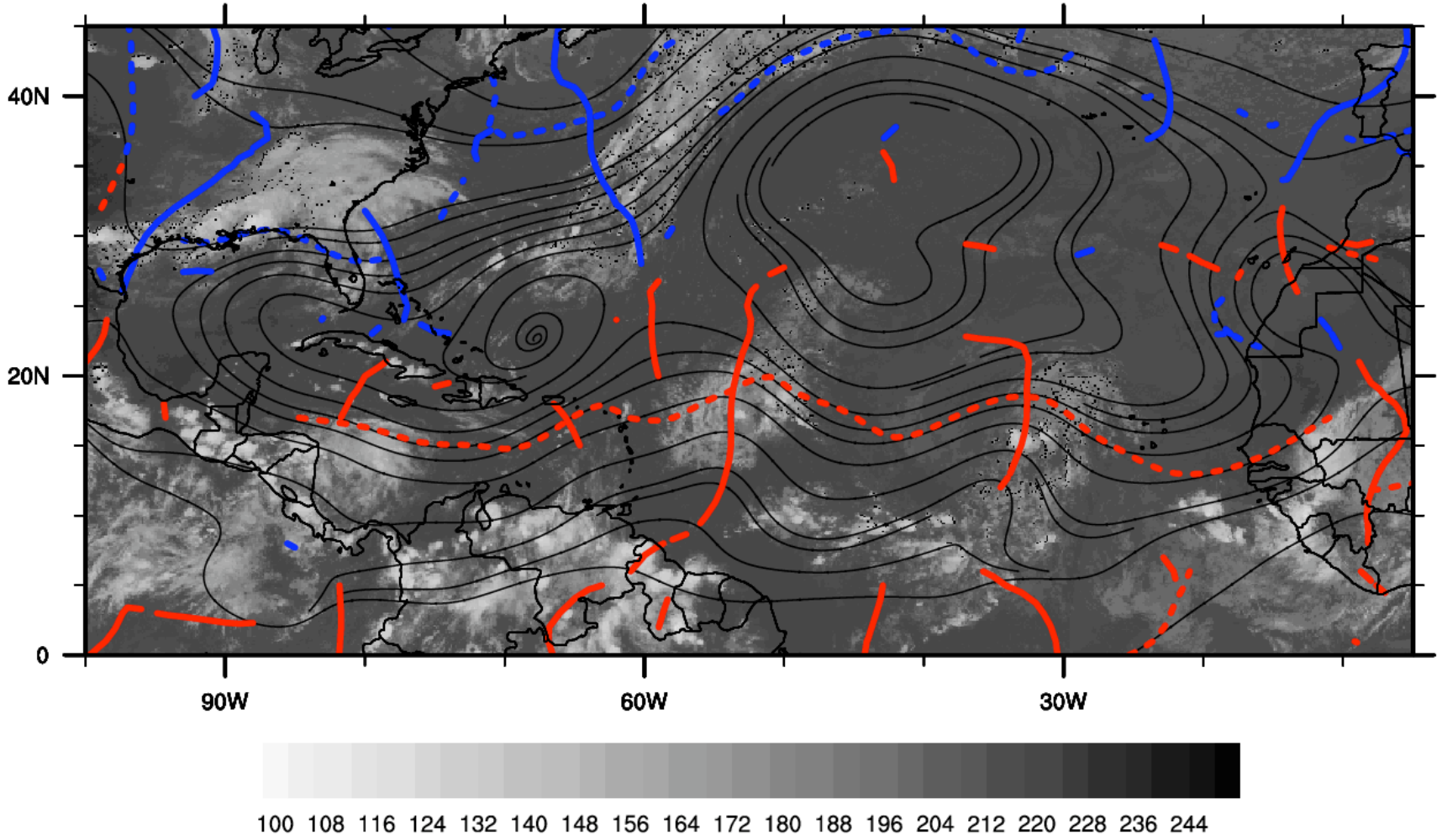
Example of the diagnostics (Aug 13th 2008) using GFS analysis:



700hPa streamlines, curvature vorticity (coloured), troughs (solid) and jets (dashed)

Diagnostics - Example.

Example of the diagnostics (Aug 13th 2008) using GFS analysis:



IR, 700hPa streamlines, troughs (solid) and jets (dashed)

Diagnostics- Current status.

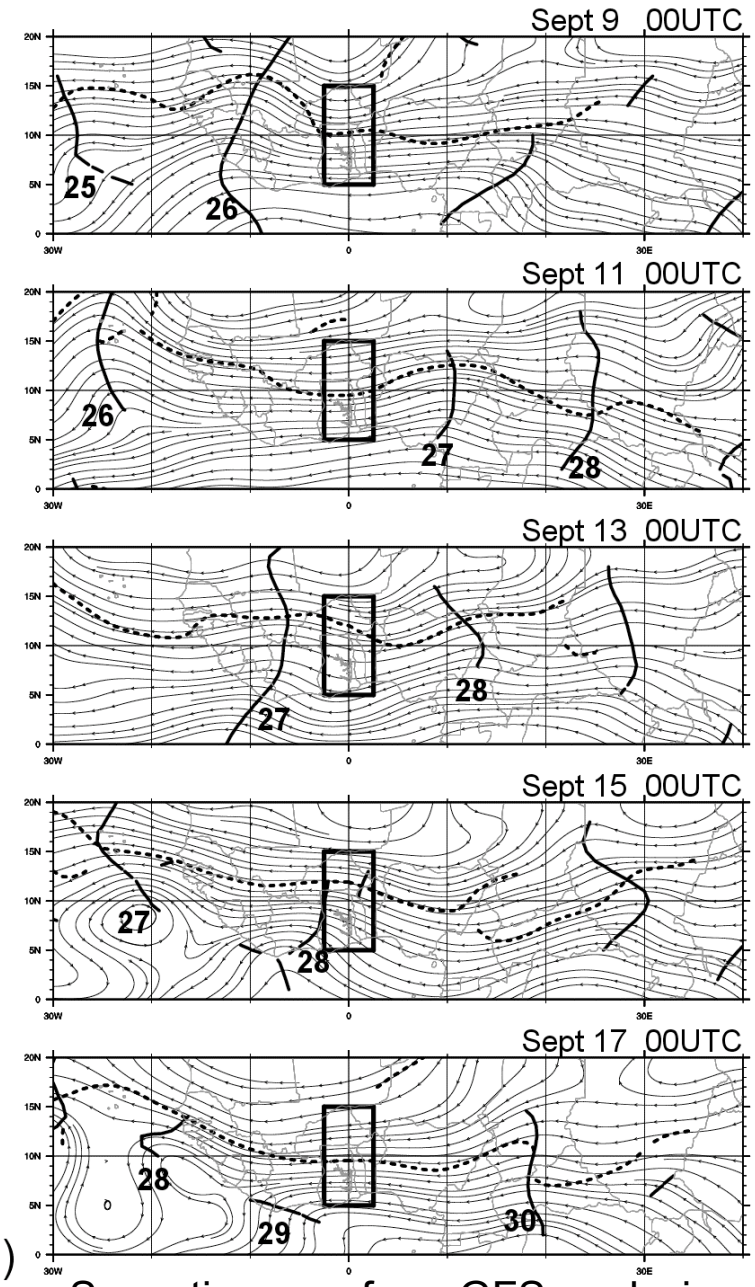
• These objective diagnostics have been produced in real time at the University at Albany from the GFS since 2004.

• They are freely available online (along with Fortran code and NCL routines): http://www.atmos.albany.edu/student/gareth/plots.html

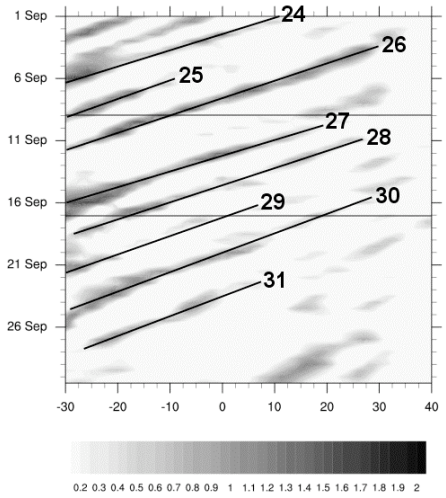
• The diagnostics are used by NWS forecasters (EYW, SJU) and at the Tropical Analysis and Forecasting Branch of the National Hurricane Center.

• These fields were used for forecasting during the AMMA field campaign (Summer 2006) and continued to be disseminated to African meteorological services via the AMMA project.

Diagnostics – Development of metrics.

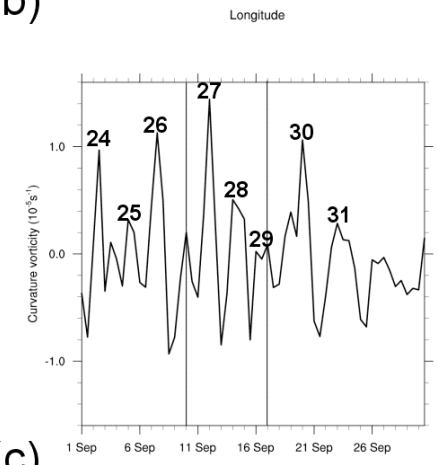


(a) Synoptic maps from GFS analysis



(b)

Hovmöller diagram of 700 hPa curvature vorticity.



(c)

Time series of 700 hPa curvature vorticity in black box

NWP model intercomparison - Introduction.

• Here we examine the representation of African easterly waves (AEWs) in four different analysis and forecasting systems from different global centres using the objective diagnostics and metrics described.

• Because of relatively sparse observations over the African continent the models are less strongly constrained and we might expect to see large differences in the analyses and forecasts.

• The aim is develop a knowledge of how similar the AEWs are in each case and if systematic differences exist between the model analyses and evaluate the model forecasts.

• To date there exists few intercomparisons of model behaviour in the west African monsoon region.

Models.

- We are going to examine AEW activity during July, August and September 2007 over the African continent in operational models from four centres:

(i) UK Met Office.

(ii) ECMWF.

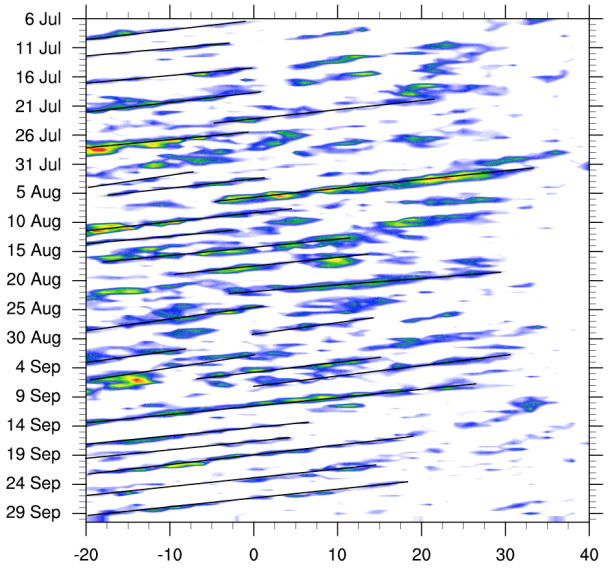
(iii) NCEP (GFS).

(iv) Meteo France (Arpege).

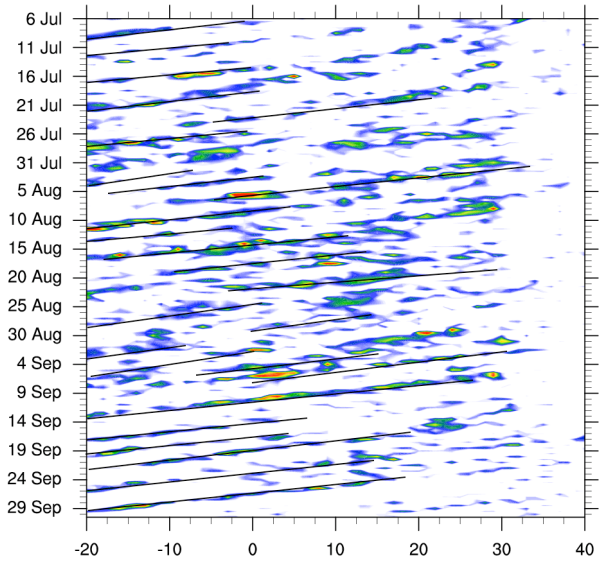
•The 00 and 12 UTC analysis times are used with forecasts every 24 hours out to 5 days (Arpege to 3 days).

• The model data are all interpolated to the same 1x1 degree grid before processing and analysis.

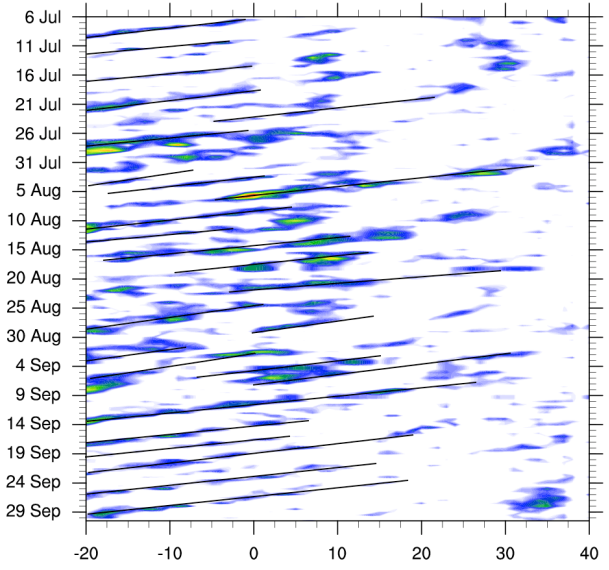
Analysis products – 700hPa curvature vorticity, averaged 5-15N over Africa.



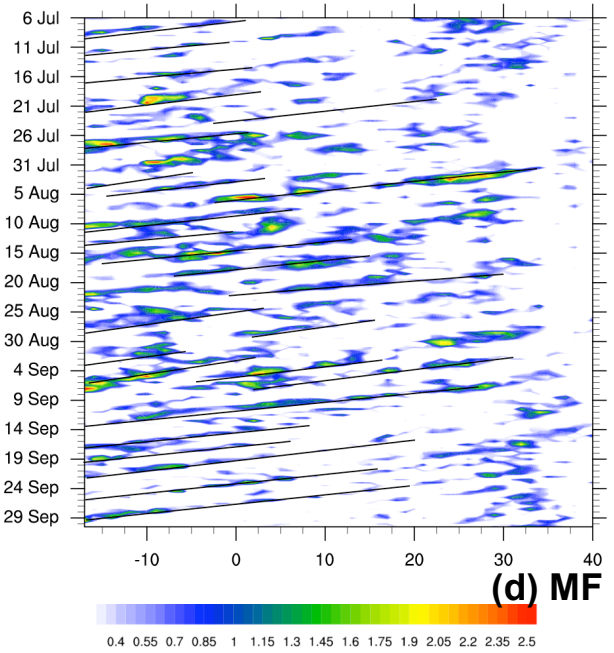
(a) ECMWF



(b) GFS



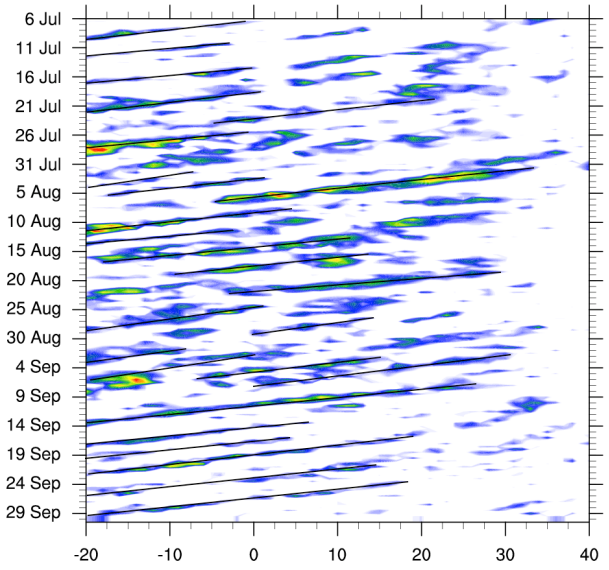
(c) UKMO



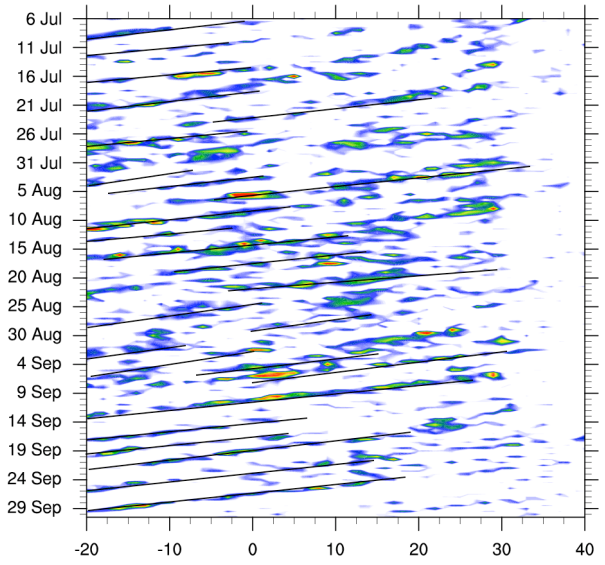
(d) MF

Subjective ‘best track’ line added for comparison.

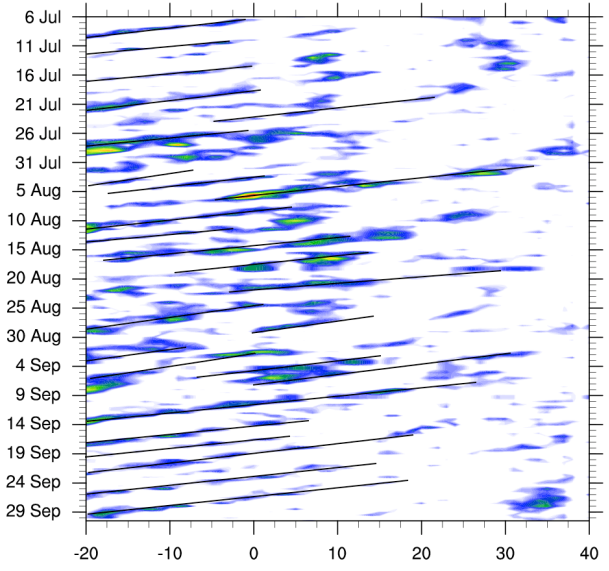
Analysis products – 700hPa curvature vorticity, averaged 5-15N over Africa.



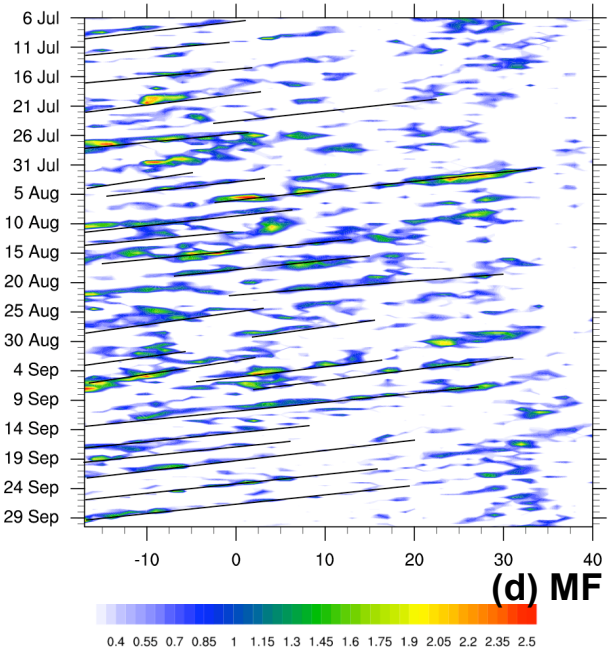
(a) ECMWF



(b) GFS



(c) UKMO

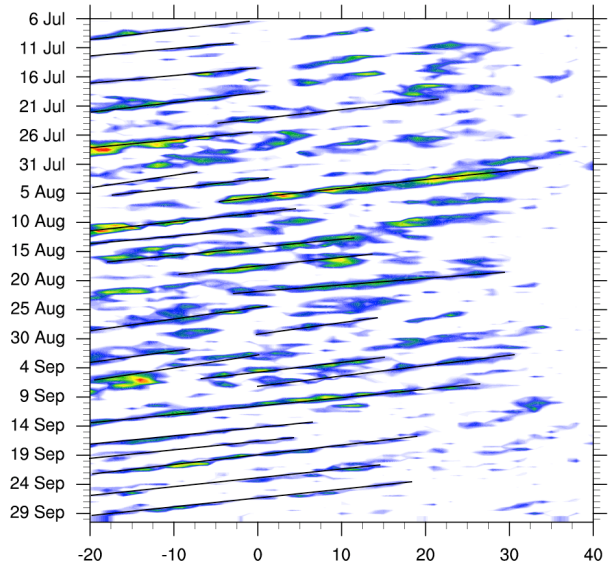


(d) MF

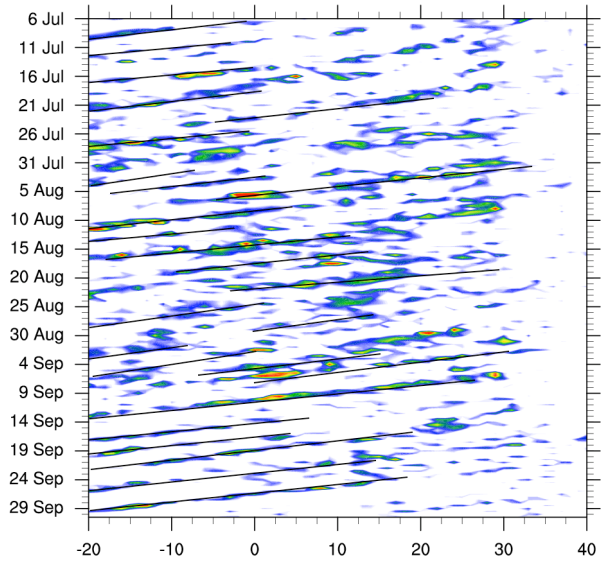
Subjective ‘best track’ line added for comparison.

- Analysis product have excellent agreement on the timing of AEWs.

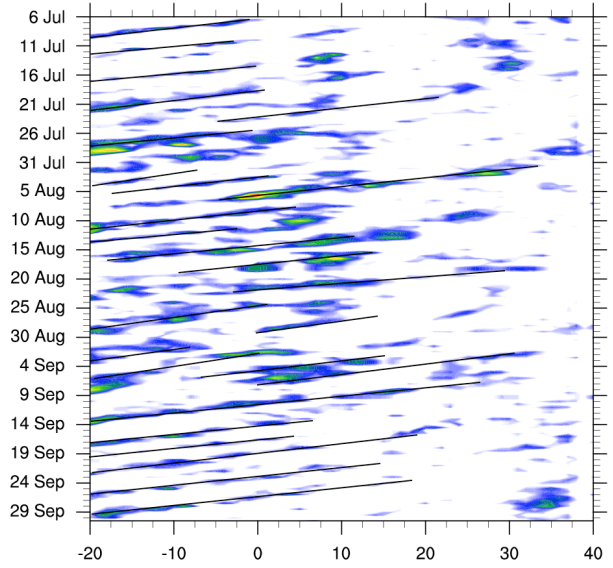
Analysis products – 700hPa curvature vorticity, averaged 5-15N over Africa.



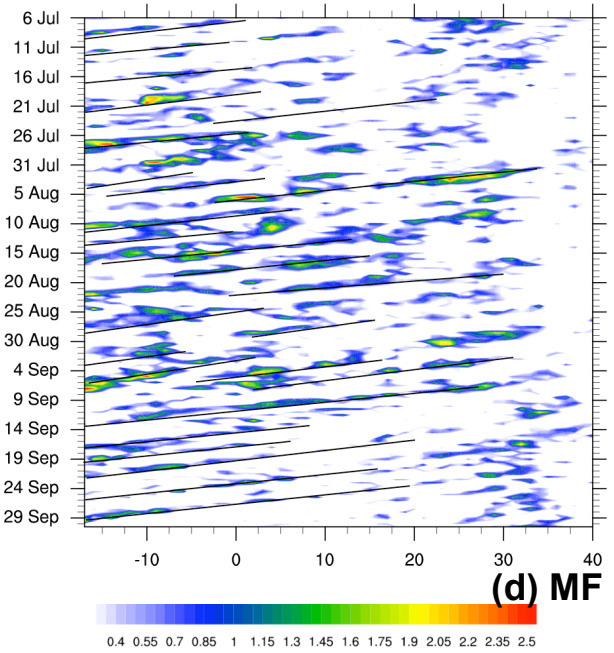
(a) ECMWF



(b) GFS



(c) UKMO

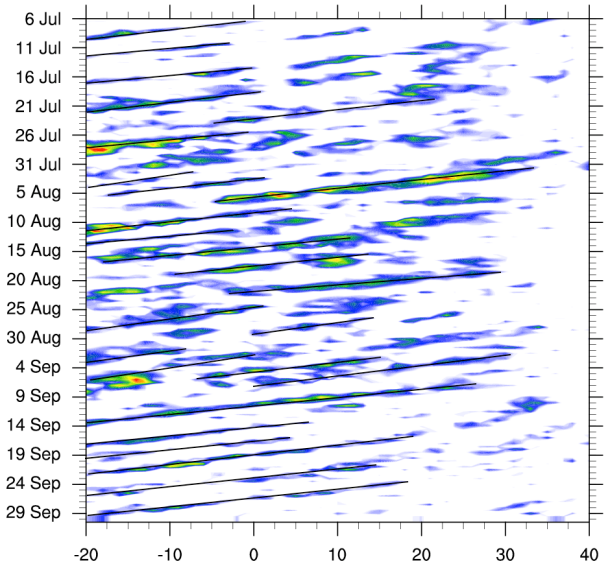


(d) MF

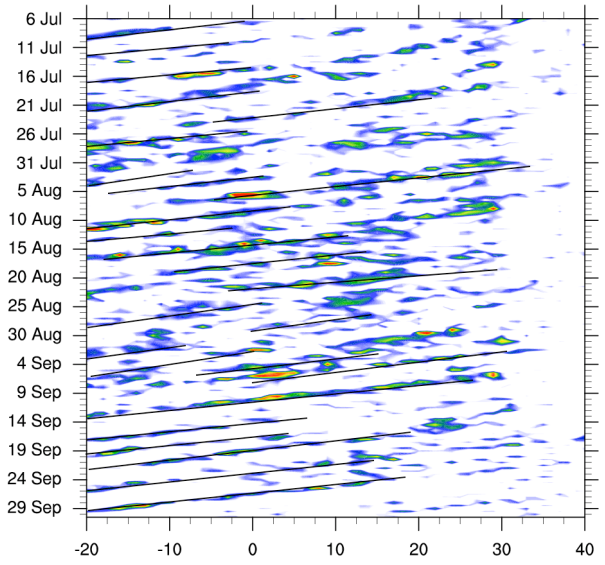
Subjective 'best track' line added for comparison.

- Analysis product have excellent agreement on the timing of AEWs.
- ECMWF and GFS have similar evolution of AEWs.

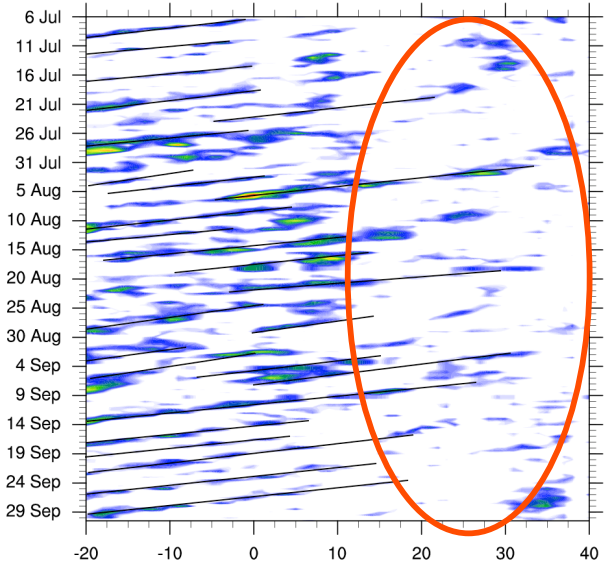
Analysis products – 700hPa curvature vorticity, averaged 5-15N over Africa.



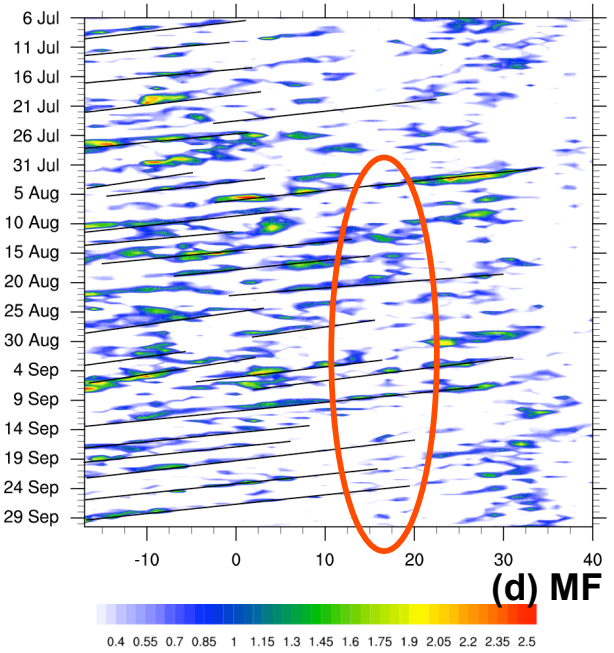
(a) ECMWF



(b) GFS



(c) UKMO

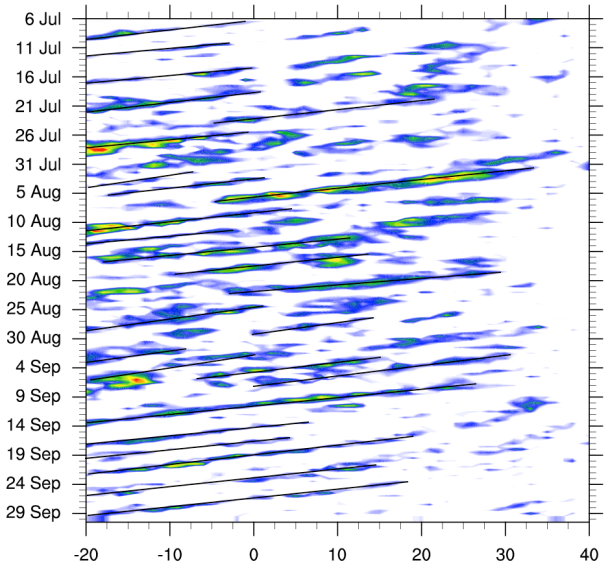


(d) MF

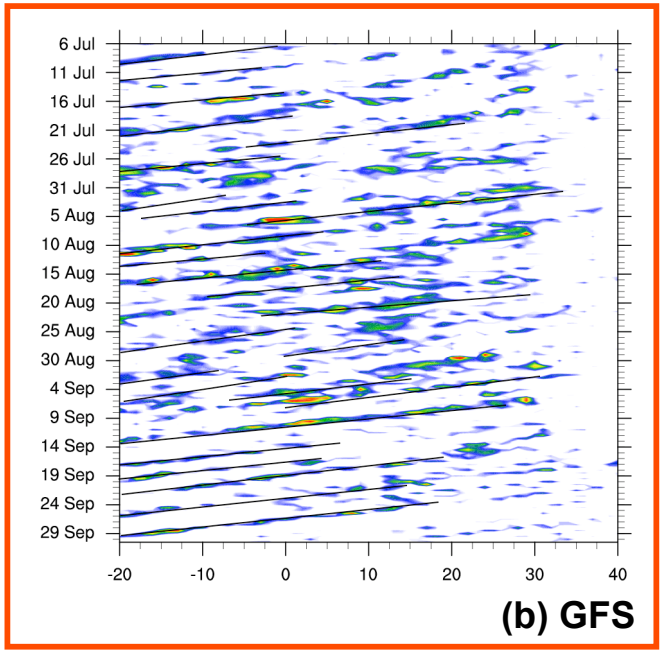
Subjective ‘best track’ line added for comparison.

- Analysis product have excellent agreement on the timing of AEWs.
- ECMWF and GFS have similar evolution of AEWs.
- The MeteoFrance (MF) and UK Met Office (UKMO) analyses have regions where the AEW ‘activity’ is low.

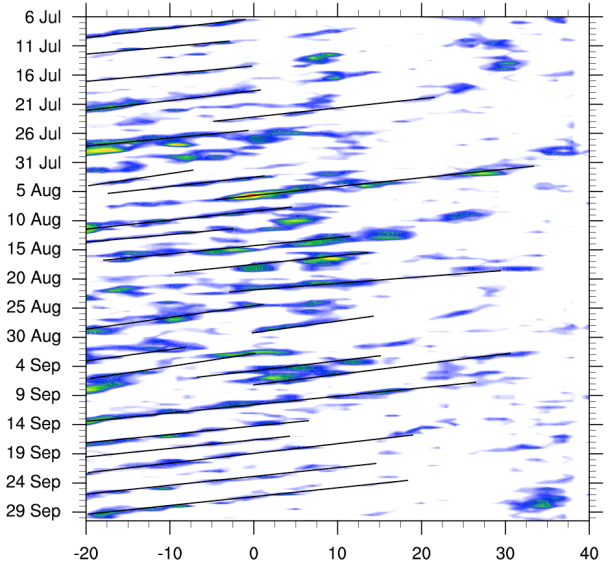
Analysis products – 700hPa curvature vorticity, averaged 5-15N over Africa.



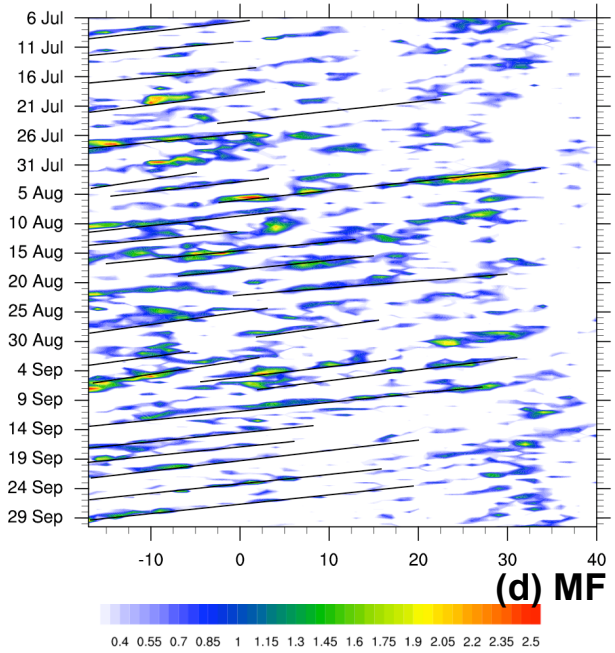
(a) ECMWF



(b) GFS



(c) UKMO

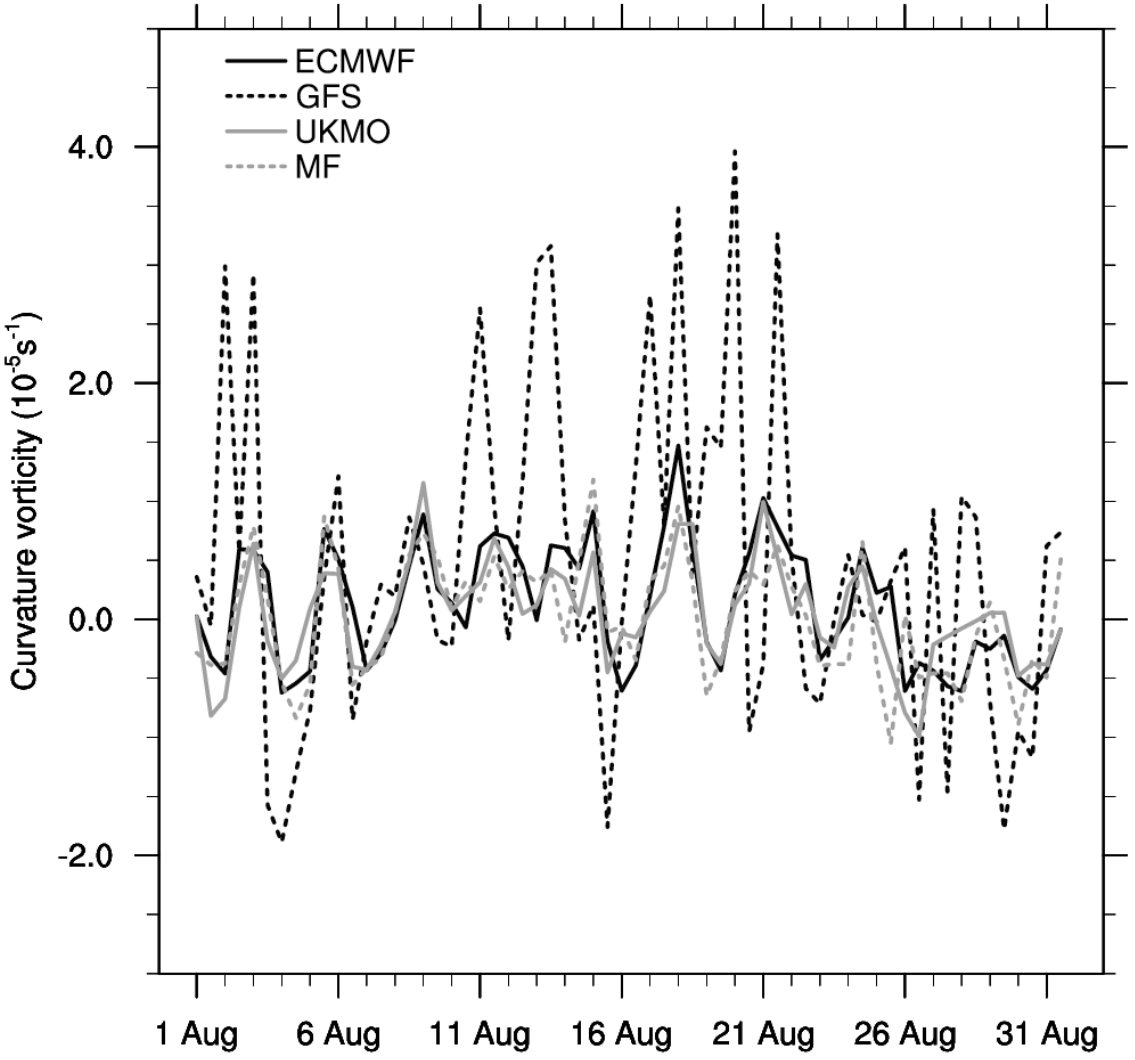


(d) MF

Subjective ‘best track’ line added for comparison.

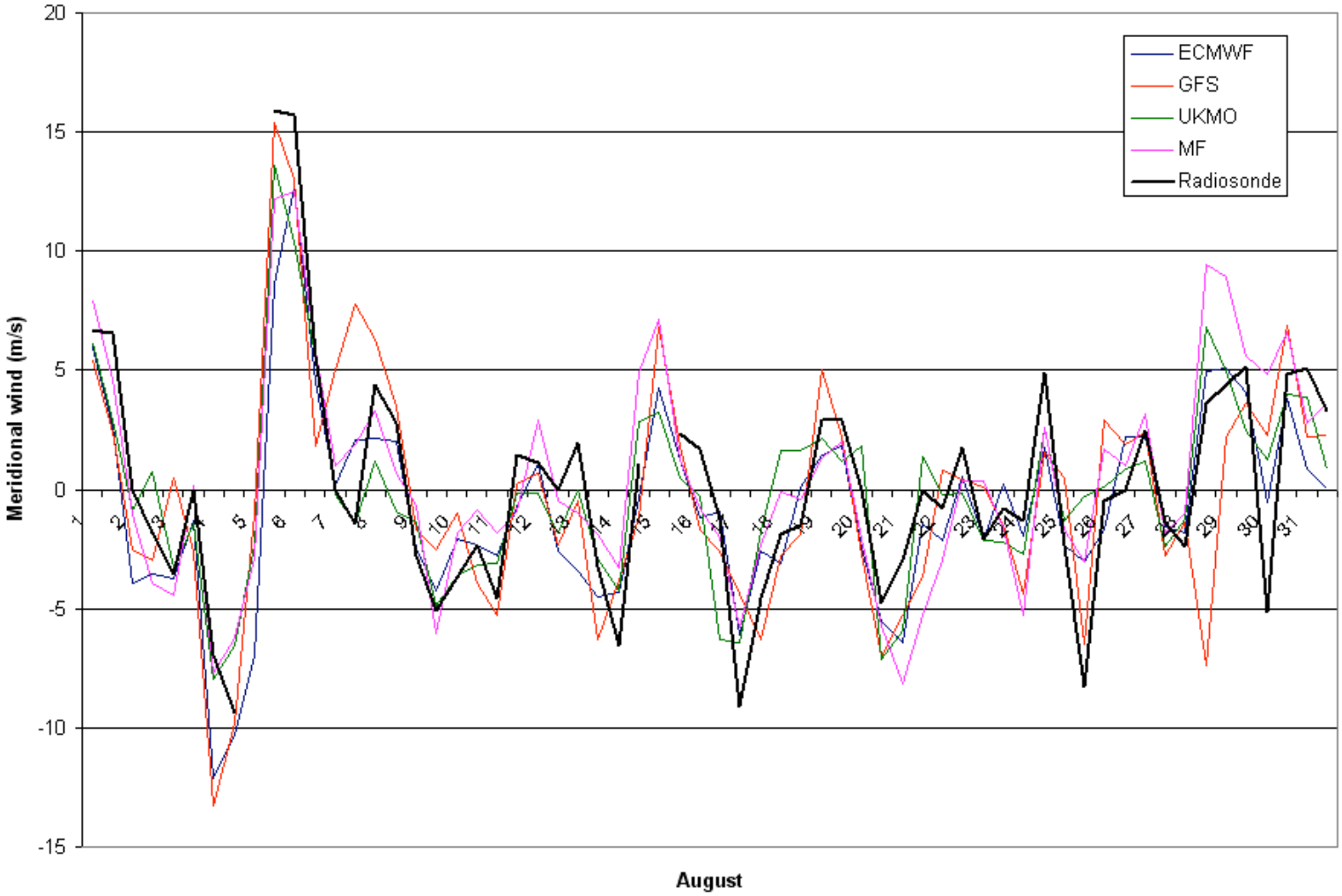
- Analysis product have excellent agreement on the timing of AEWs.
- ECMWF and GFS have similar evolution of AEWs.
- The MeteoFrance (MF) and UK Met Office (UKMO) analyses have regions where the AEW ‘activity’ is low.
- Curvature vorticity maxima are largest in the GFS.

Analysis products – 700hPa curvature vorticity time series in box at the Greenwich meridian (5-15N, 2.5W-2.5E).



- ECMWF, UKMO and MF Time series are highly correlated ($r > 0.7$).
- Variance of the GFS time series is three times larger than any of the others.
- Correlation of GFS with others is ($r<0.4$).

Meridional wind at 700hPa at nearest grid point to Niamey, Niger (13.48N, 2.16E)



- Compared with Niamey radiosonde and one another, all four analyses have approximately r = 0.8.
- Hypothesize that the difference seen in the GFS is related to horizontal structure of wind field, as curvature vorticity depends on horizontal gradients of the wind field.

Mean evolution of AEWs in the analyses and their relationship with precipitation.

• To look at the mean evolution of AEWs in the analyses, the lag regression technique employed by Kiladis et al (2006) is used.

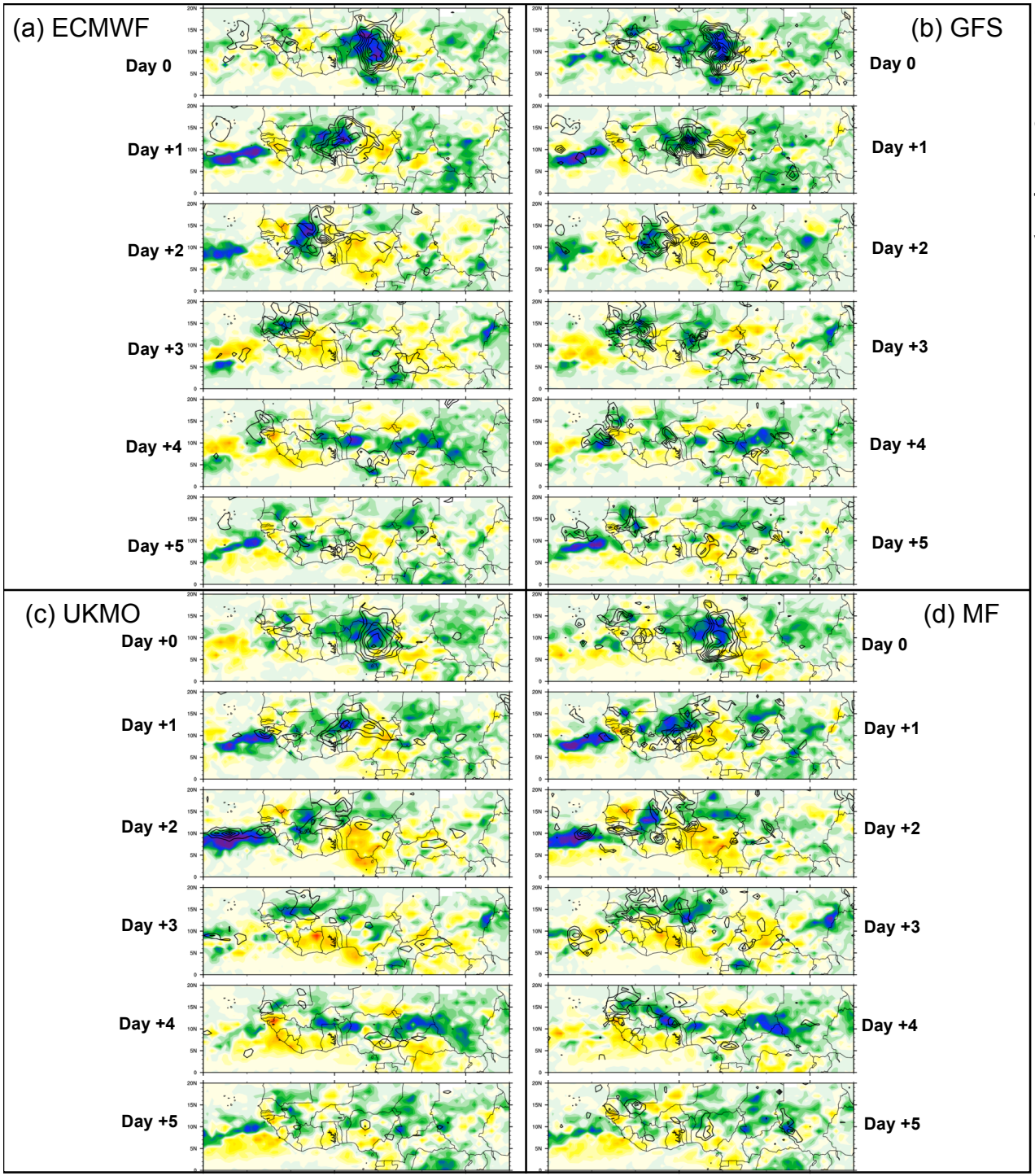
• This involves using the lagged projections of time series of model grid point data linearly regressed against some base time series.

• The base time series chosen is the mean 700hPa curvature vorticity 5-15N, 7.5E-12.5E, which is 4-5 days upstream of the West African coast.

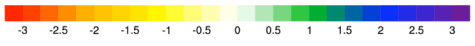
• This base time series is linearly regressed against time series at each point in the model domain and multiplied against the standard deviation of the grid point time series to give physically meaningful quantities.

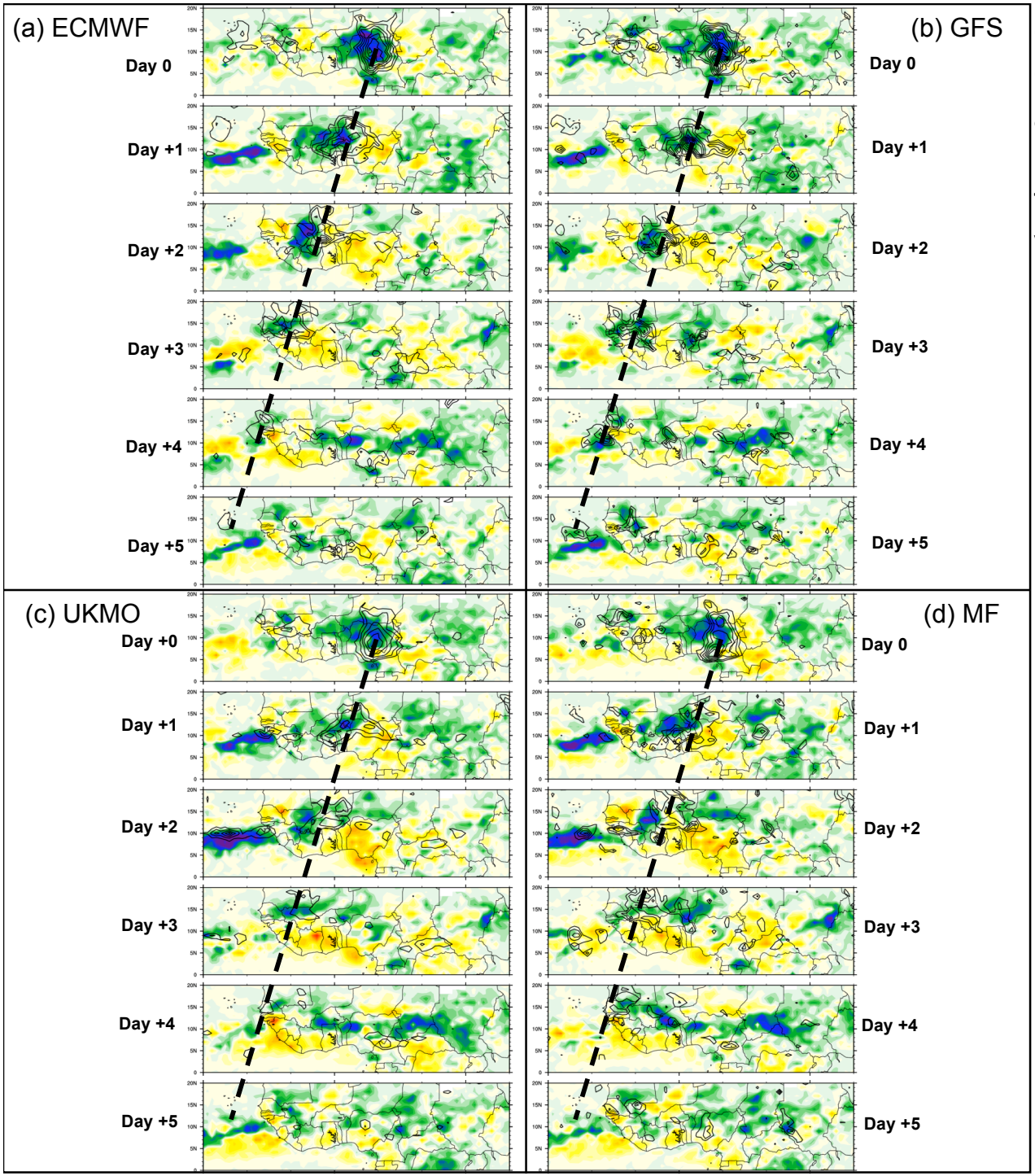
• This is performed at various time lags to give a composite evolution over time and space.

• Because the precipitation rate is absent in some analysis products, the CMORPH satellite estimate is substituted.



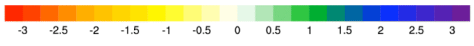
Composite evolution of CMORPH precipitation (colours) and 700hPa curvature vorticity (positive values contoured). Base time series: 700hPa curvature vorticity averaged 5-15N, 7.5-12.5E)



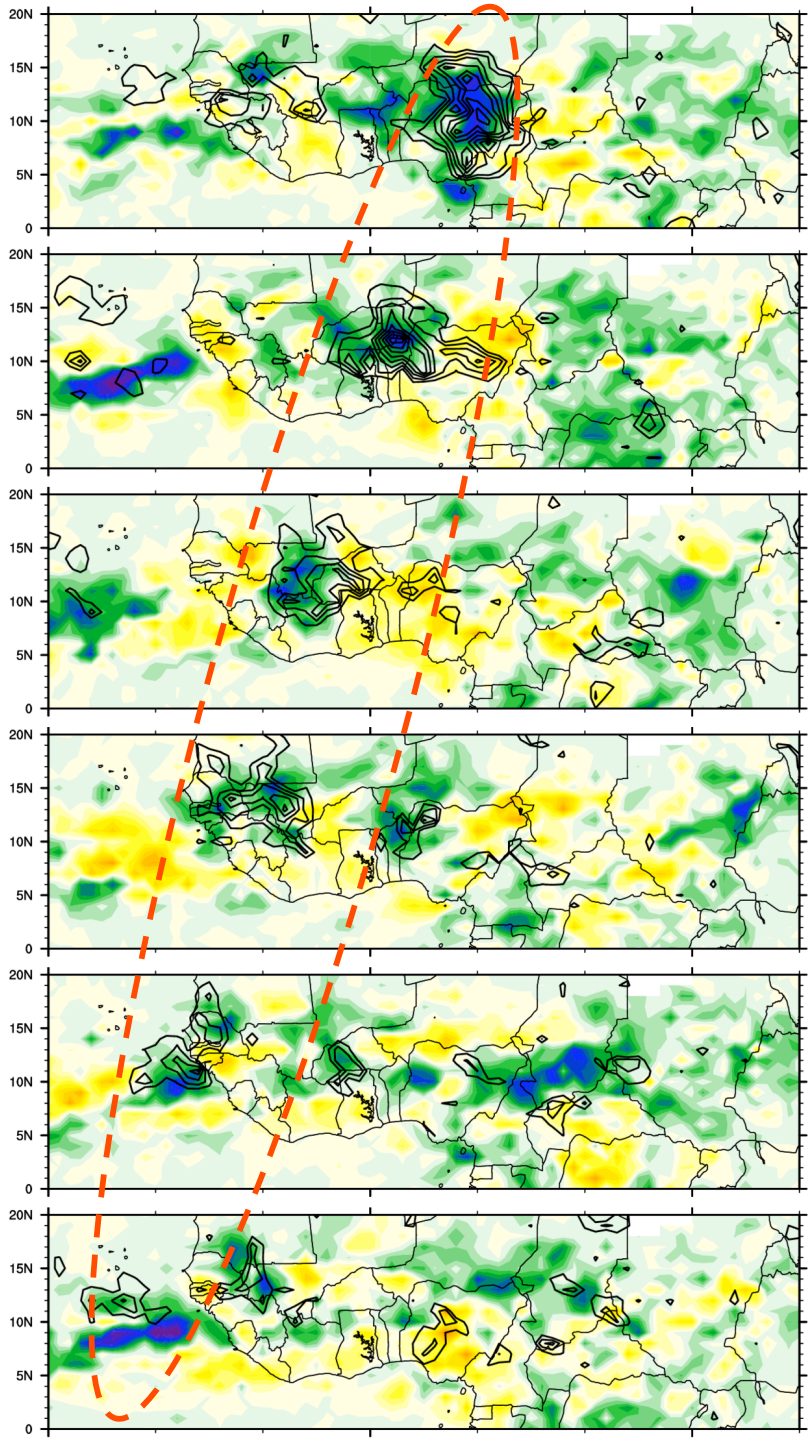


Composite evolution of CMORPH precipitation (colours) and 700hPa curvature vorticity (positive values contoured). Base time series: 700hPa curvature vorticity averaged 5-15N, 7.5-12.5E)

- AEW has the same phase speed in all.



GFS:



Day 0

Day +1

Day +2

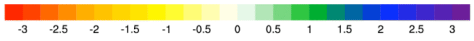
Day +3

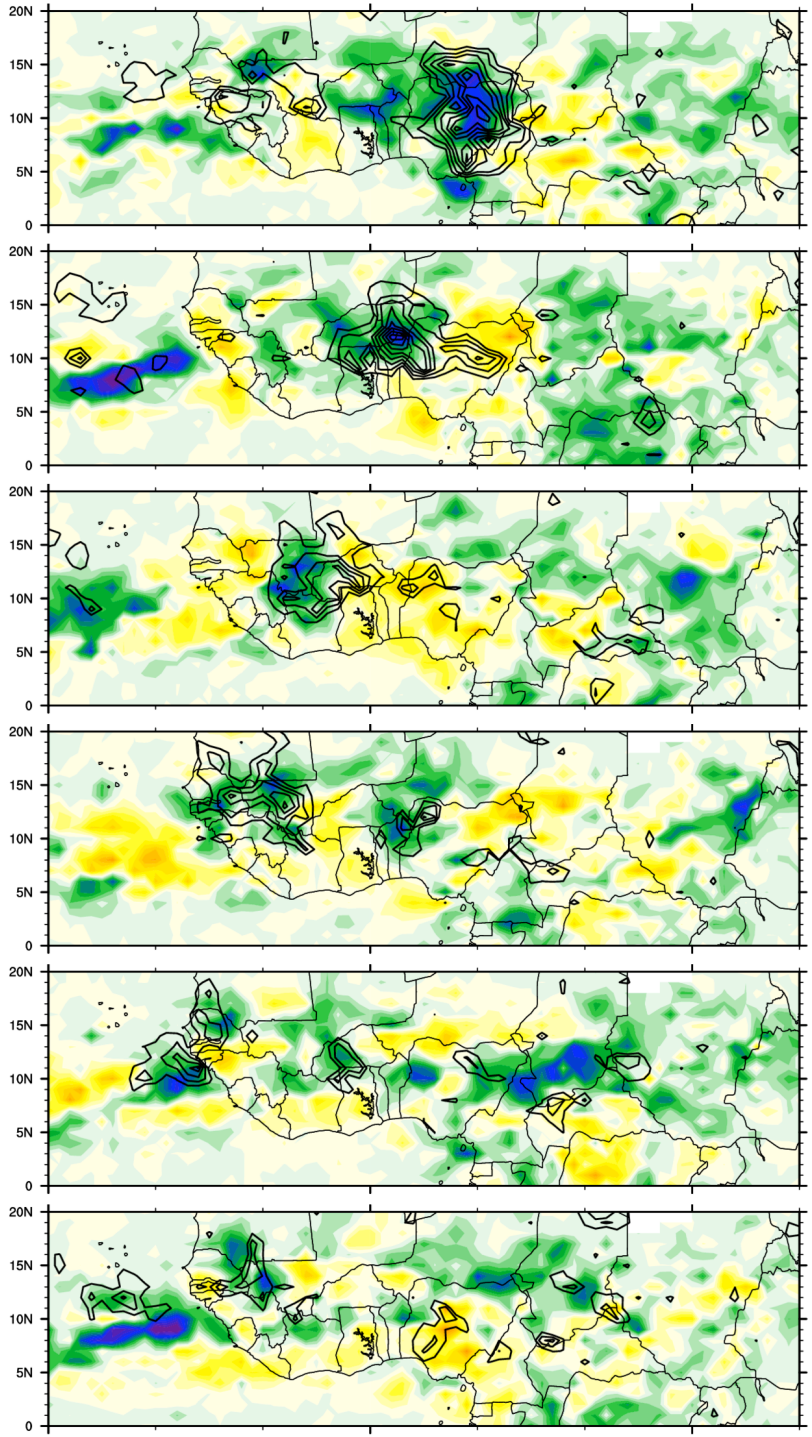
Day +4

Day +5

Composite evolution of CMORPH precipitation (colours) and 700hPa curvature vorticity (positive values contoured). Base time series: 700hPa curvature vorticity averaged 5-15N, 7.5-12.5E)

- AEW has the same phase speed in all.
- GFS has the strongest composite AEW. UKMO has the weakest.





Day 0

Day +1

Day +2

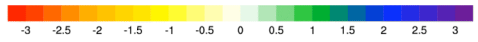
Day +3

Day +4

Day +5

Composite evolution of CMORPH precipitation (colours) and 700hPa curvature vorticity (positive values contoured). Base time series: 700hPa curvature vorticity averaged 5-15N, 7.5-12.5E)

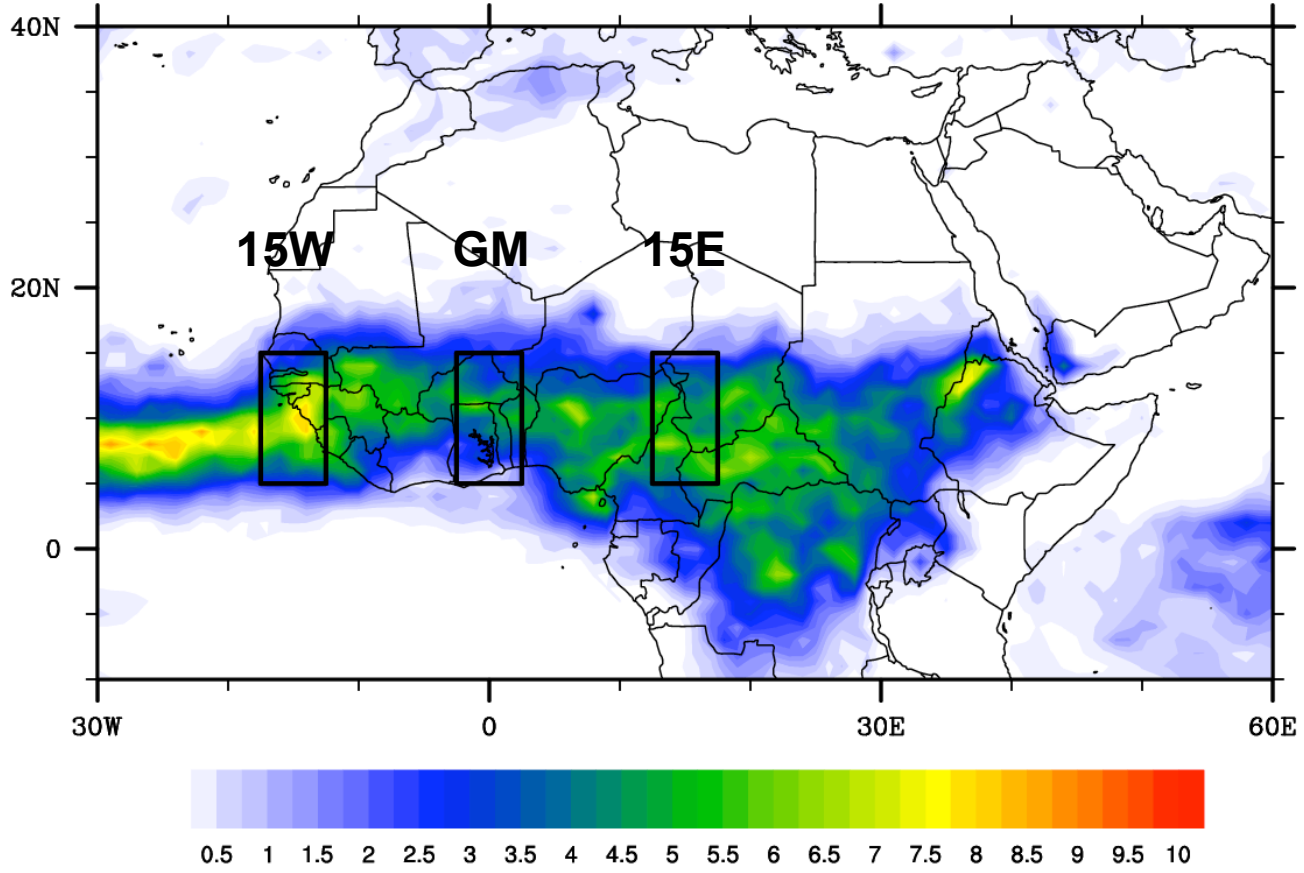
- AEW has the same phase speed in all.
- GFS has the strongest composite AEW. UKMO has the weakest.
- Initially the precipitation is in the leading half of the AEW, but shifts closer to its centre by day+3.



Forecast products – verification of 700hPa curvature vorticity forecasts.

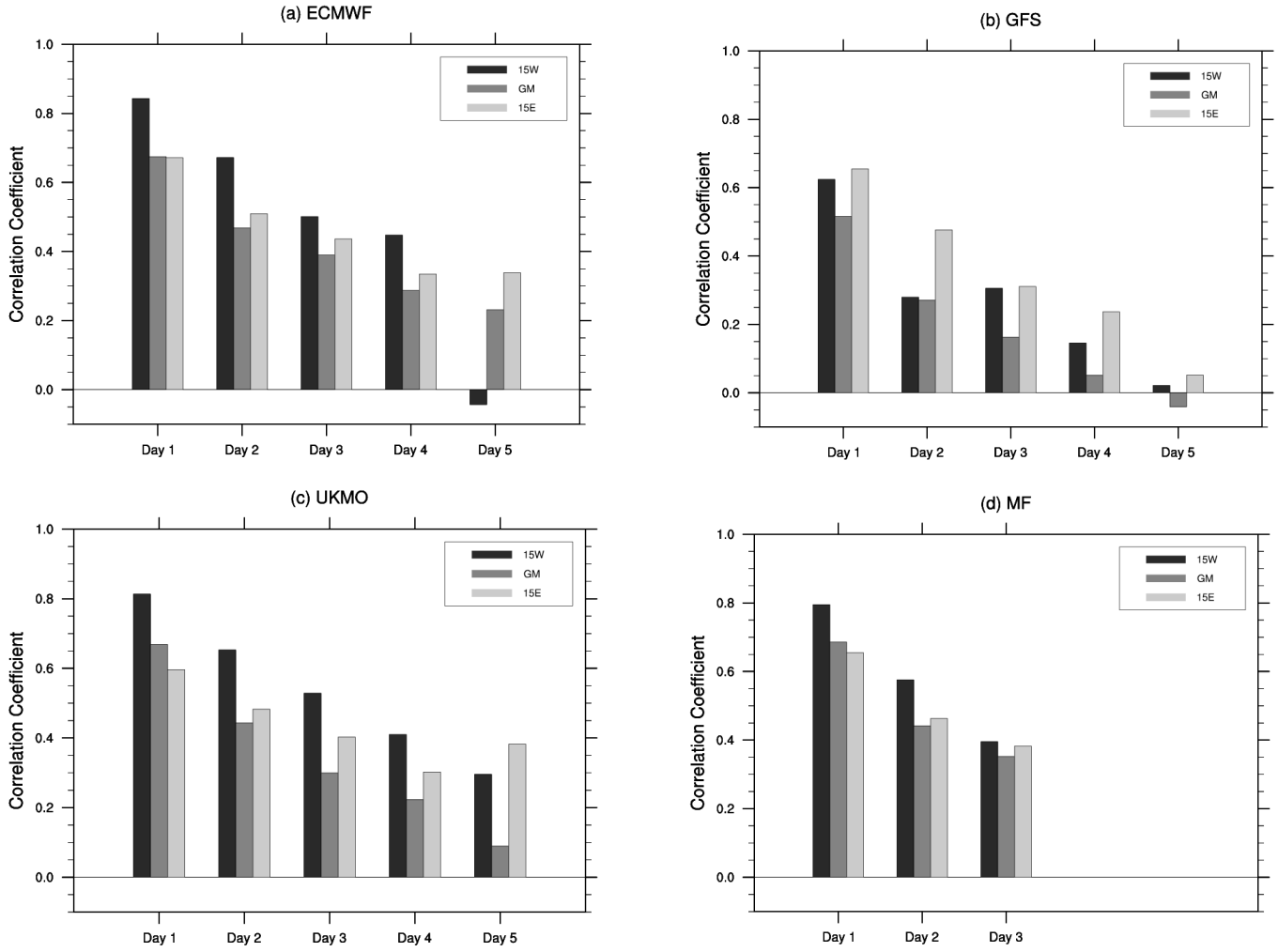
• Forecasts are verified against their equivalent analysis from the same model.

• Initially the metric used is the correlation of 700hPa curvature vorticity time series in the three boxes shown below.



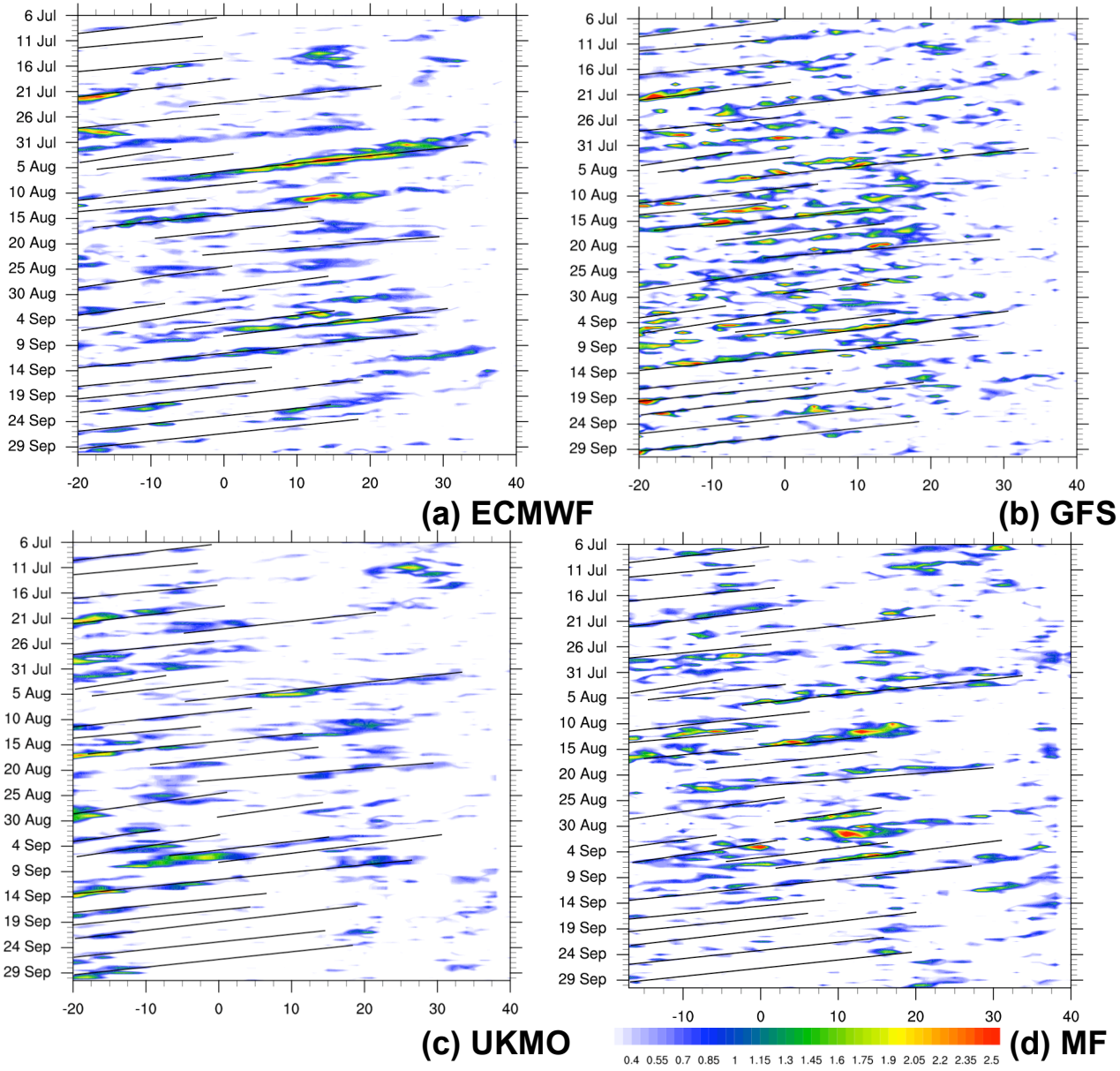
Mean CMORPH precipitation (mm/day)

Forecast products – verification of 700hPa curvature vorticity forecasts.



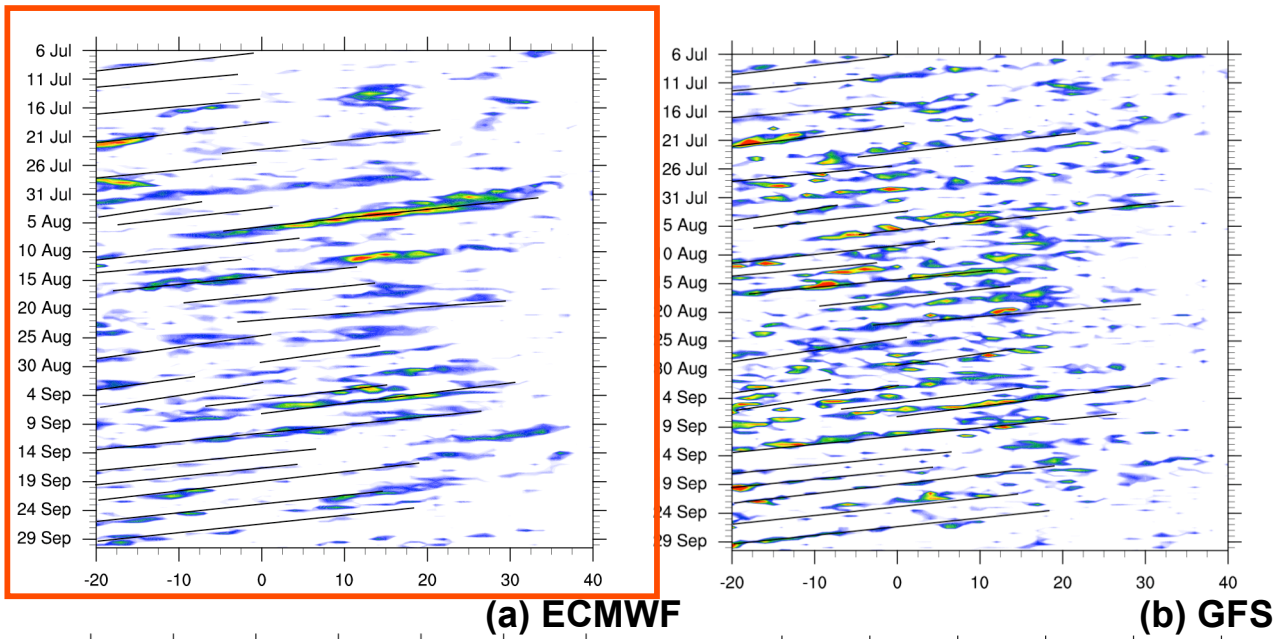
- All coefficients <0.5 after 3 days.
- Relatively high correlations in the east, despite lack of observations.
- Note that in data sparse regions this verification method can reward persistence, not necessarily skill!

Forecast products – Synoptic characteristics.



Hovmöller diagrams of 700hPa curvature vorticity, comprised entirely of day 3 forecasts.

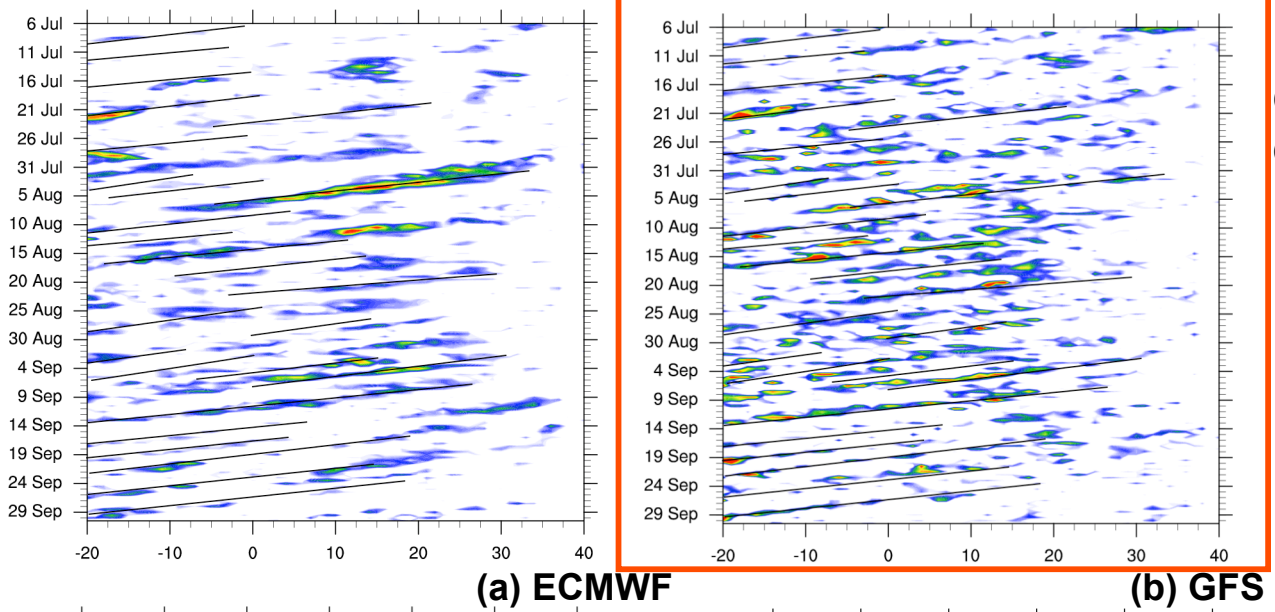
Forecast products – Synoptic characteristics.



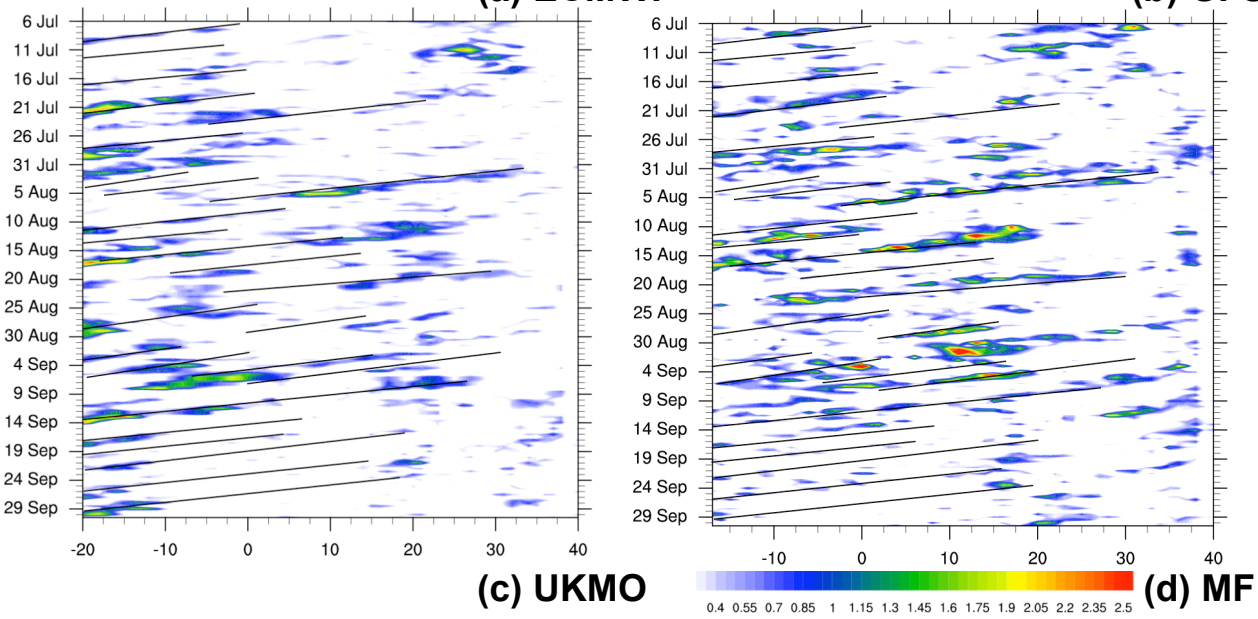
Hovmöller diagrams of 700hPa curvature vorticity, comprised entirely of day 3 forecasts.

- In ECMWF forecasts the AEWs tend to be too weak.

Forecast products – Synoptic characteristics.



(a) ECMWF (b) GFS

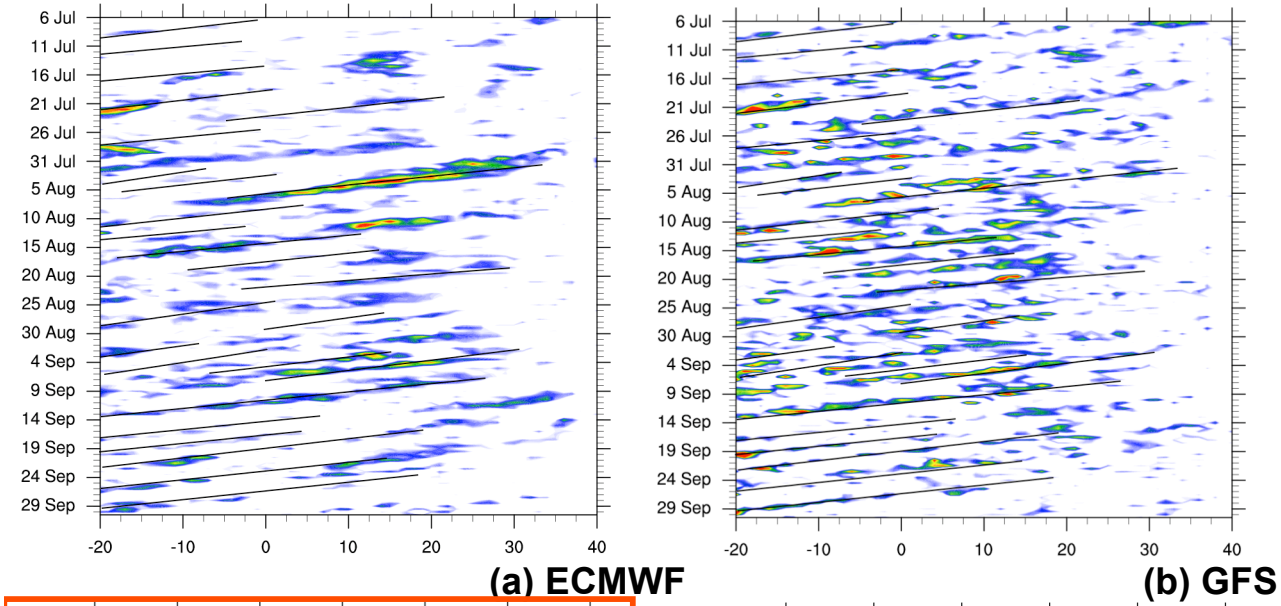


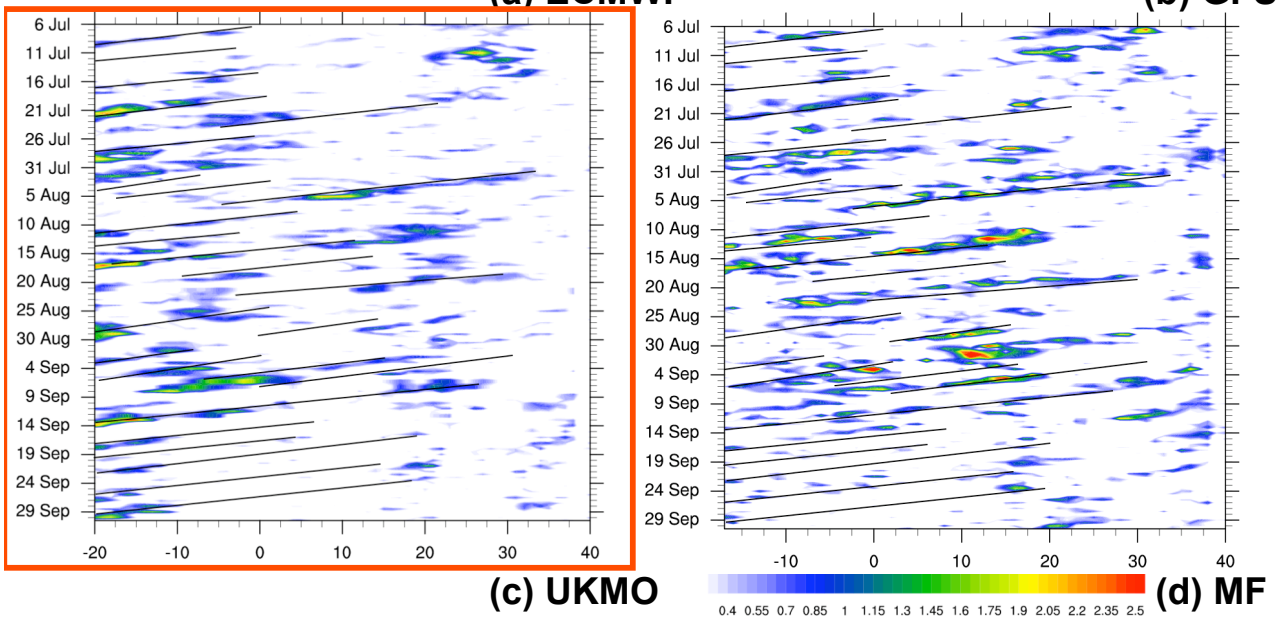
(c) UKMO (d) MF

Hovmöller diagrams of 700hPa curvature vorticity, comprised entirely of day 3 forecasts.

- In ECMWF forecasts the AEWs tend to be too weak.
- In the GFS the AEWs tend to be too strong with increased sub-synoptic scale maxima.

Forecast products – Synoptic characteristics.

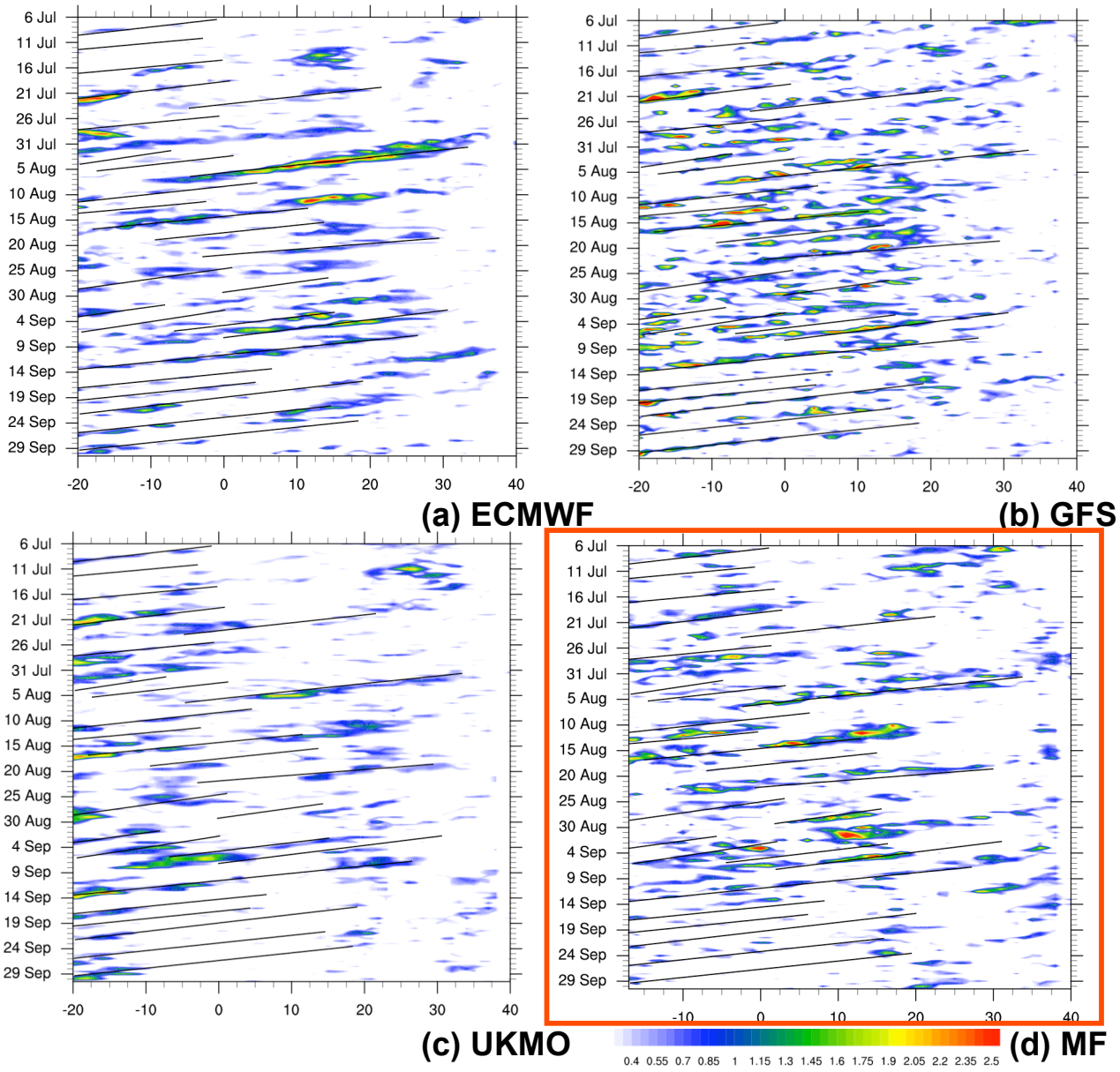




Hovmöller diagrams of 700hPa curvature vorticity, comprised entirely of day 3 forecasts.

- In ECMWF forecasts the AEWs tend to be too weak.
- In the GFS the AEWs tend to be too strong with increased sub-synoptic scale maxima.
- The UKMO forecasts tend to advect the initial conditions and struggle to generate new AEWs

Forecast products – Synoptic characteristics.



Hovmöller diagrams of 700hPa curvature vorticity, comprised entirely of day 3 forecasts.

- In ECMWF forecasts the AEWs tend to be too weak.
- In the GFS the AEWs tend to be too strong with increased sub-synoptic scale maxima.
- The UKMO forecasts tend to advect the initial conditions and struggle to generate new AEWs
- The MF forecasts also struggle to generate new AEWs and also make the existing ones too intense.

Forecast products – Systematic drift.

• The 2-6 day filtered variance of the 700hPa curvature vorticity field in both the forecast and analyses is used as an indicator of synoptic activity.

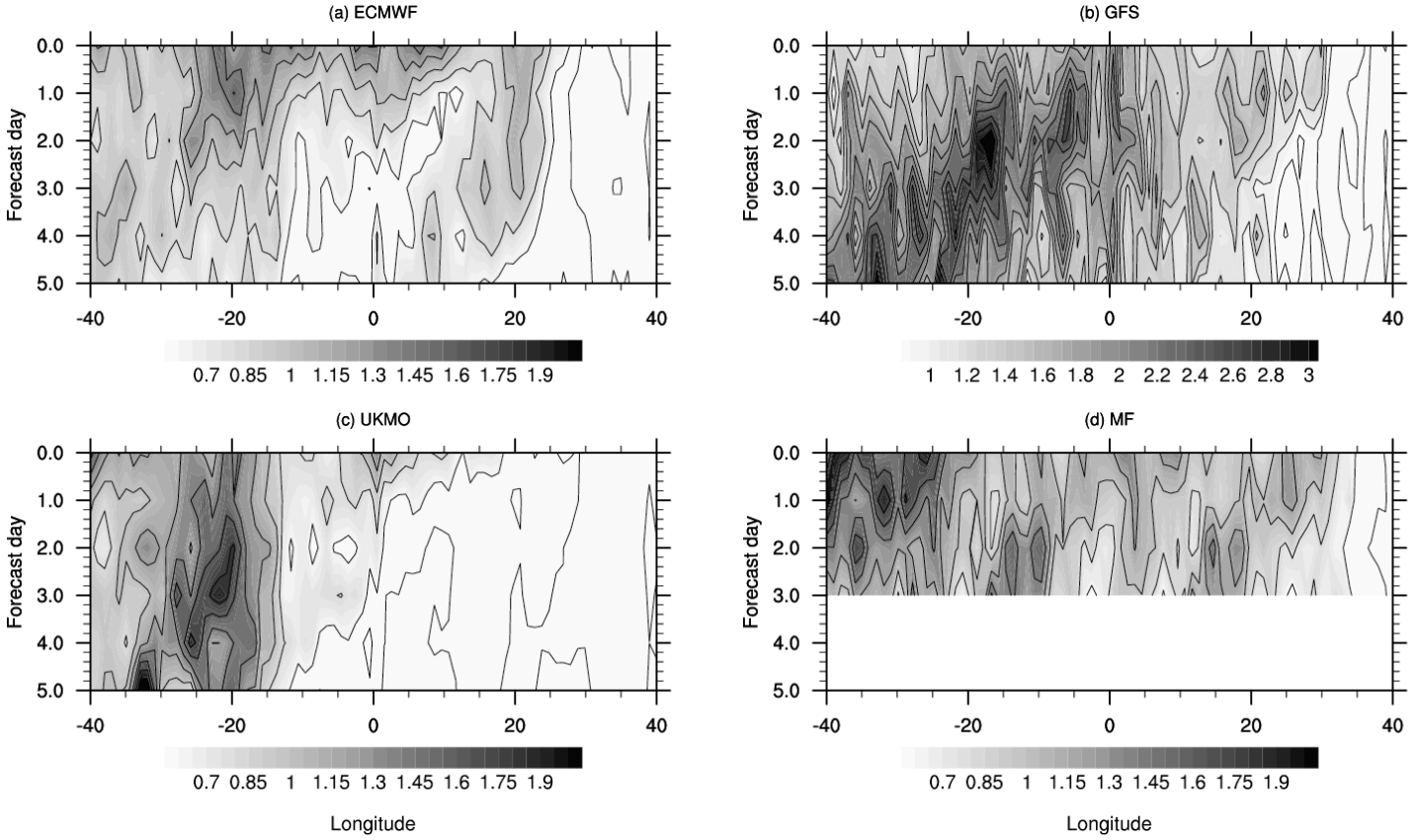
• The data are averaged 5-15N and plotted as a function of forecast lead time and longitude.

• If the forecasts are perfect (with respect to their corresponding analyses), the diagram would look like a series of straight (vertical) contours.

• Any systematic drift in the synoptic activity would be evident as deviations from the straight contours.

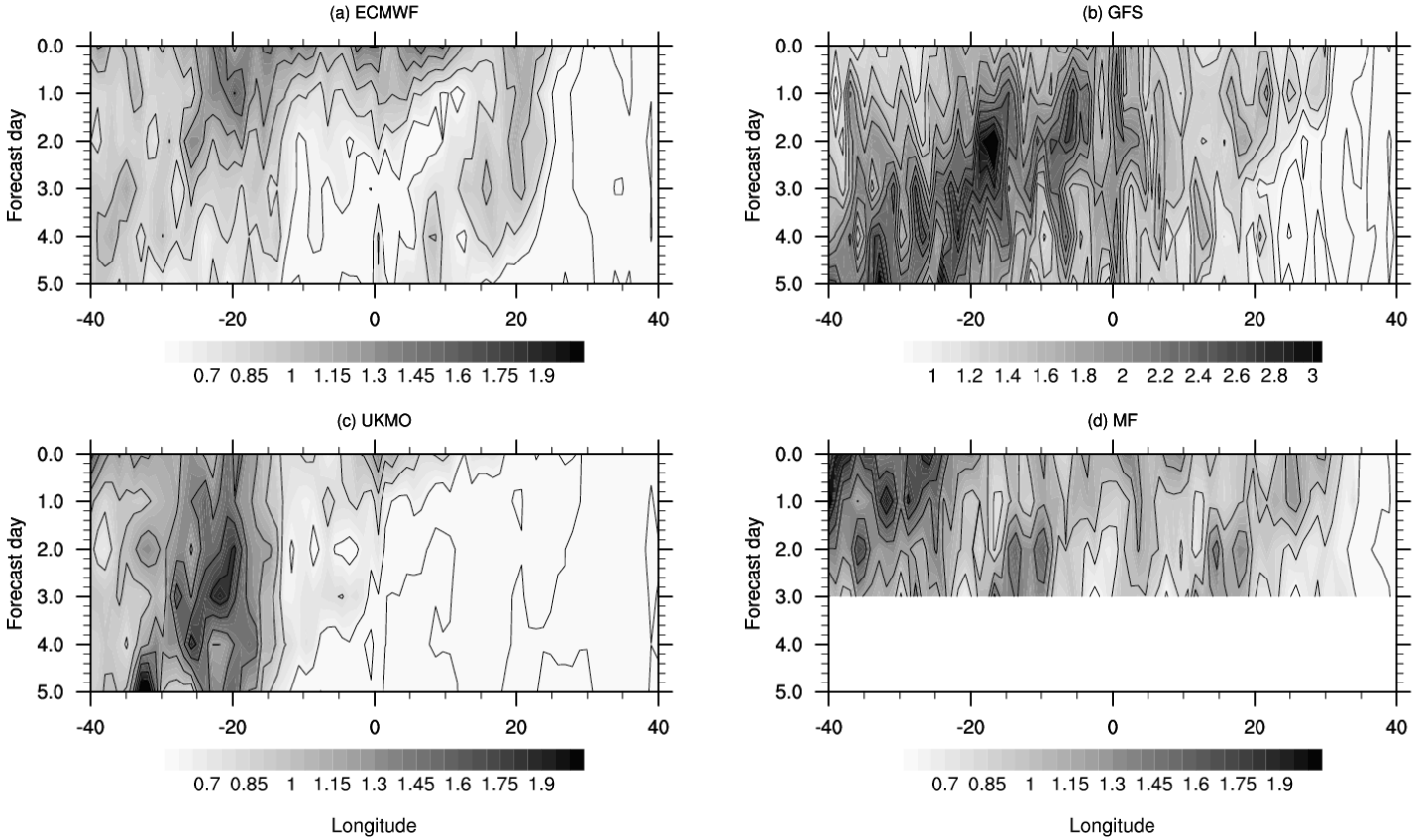
Forecast products – Systematic drift.

Mean 2 to 6 day filtered variance of 700hPa curvature vorticity, averaged 5-15N and shown as a function of longitude (westerly defined as negative) and forecast lead time.



Forecast products – Systematic drift.

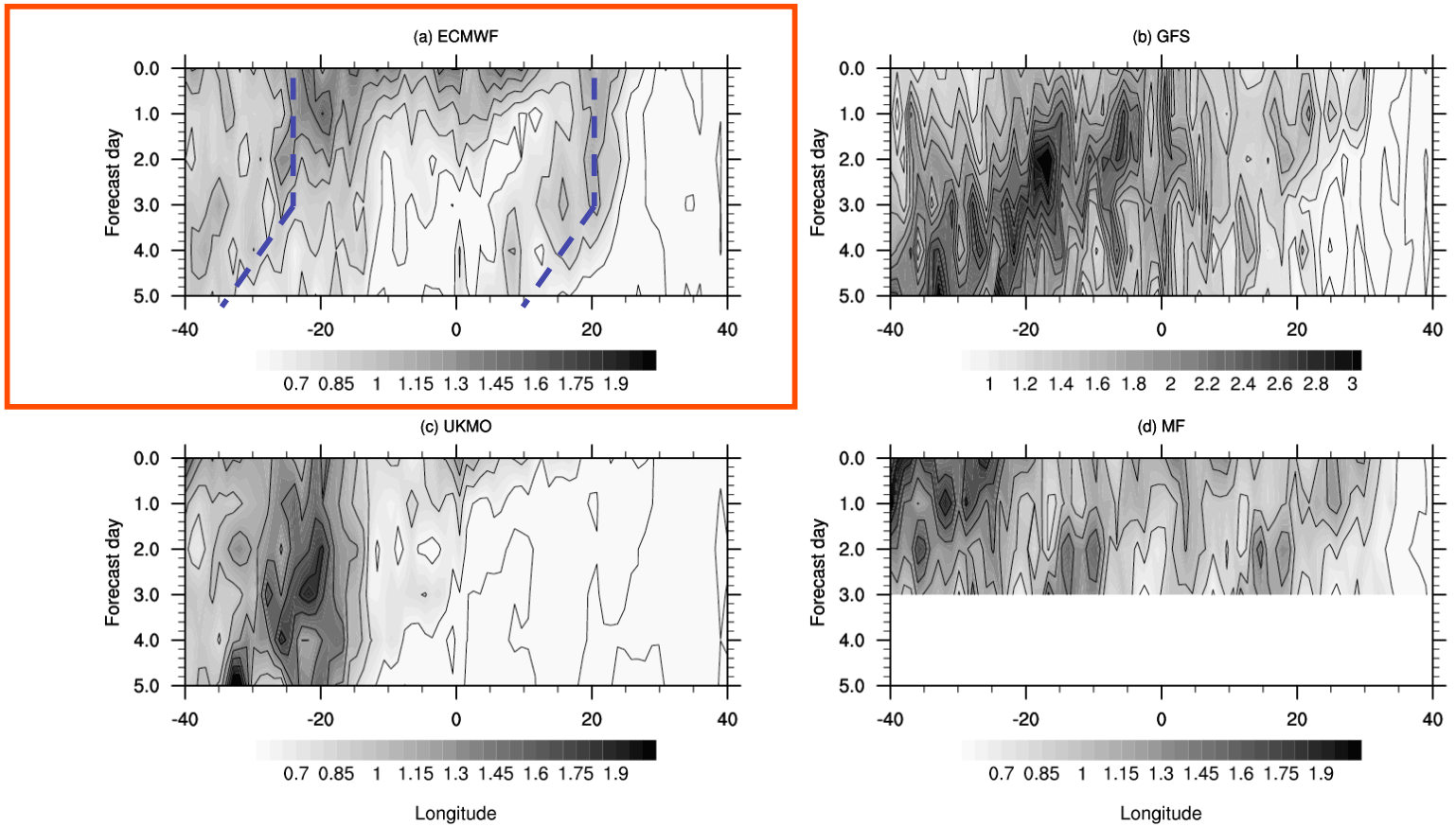
Mean 2 to 6 day filtered variance of 700hPa curvature vorticity, averaged 5-15N and shown as a function of longitude (westerly defined as negative) and forecast lead time.



- Systematic westward drift of synoptic activity during the forecast cycle is evident in all models.

Forecast products – Systematic drift.

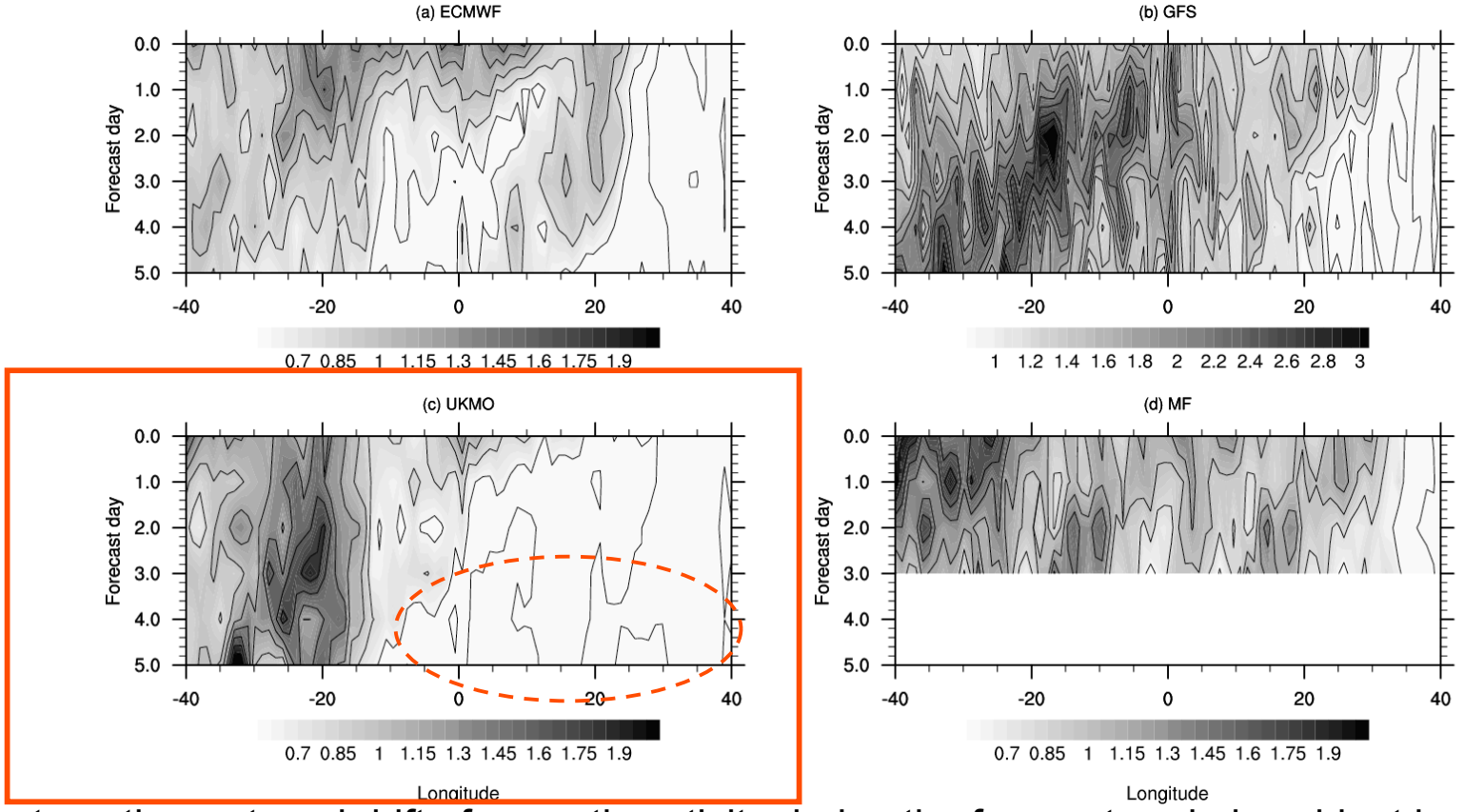
Mean 2 to 6 day filtered variance of 700hPa curvature vorticity, averaged 5-15N and shown as a function of longitude (westerly defined as negative) and forecast lead time.



- Systematic westward drift of synoptic activity during the forecast cycle is evident in all models.
- In the ECMWF forecasts the activity initially weakens then begins to drift near day 3.

Forecast products – Systematic drift.

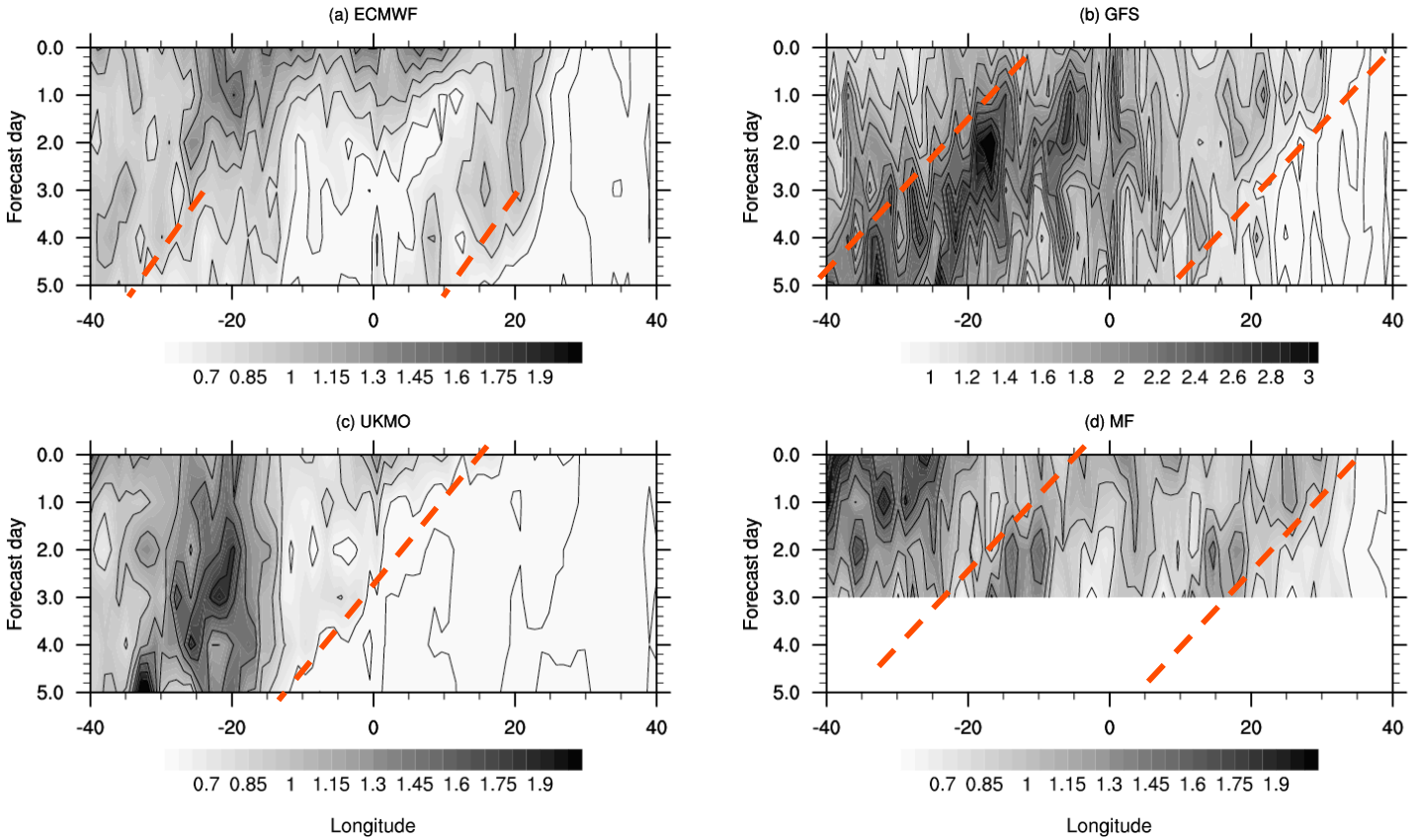
Mean 2 to 6 day filtered variance of 700hPa curvature vorticity, averaged 5-15N and shown as a function of longitude (westerly defined as negative) and forecast lead time.



- Systematic westward drift of synoptic activity during the forecast cycle is evident in all models.
- In the ECMWF forecasts the activity initially weakens then begins to drift near day 3.
- In the UKMO forecasts there is almost no synoptic activity left over Africa by day 5.

Forecast products – Systematic drift.

Mean 2 to 6 day filtered variance of 700hPa curvature vorticity, averaged 5-15N and shown as a function of longitude (westerly defined as negative) and forecast lead time.

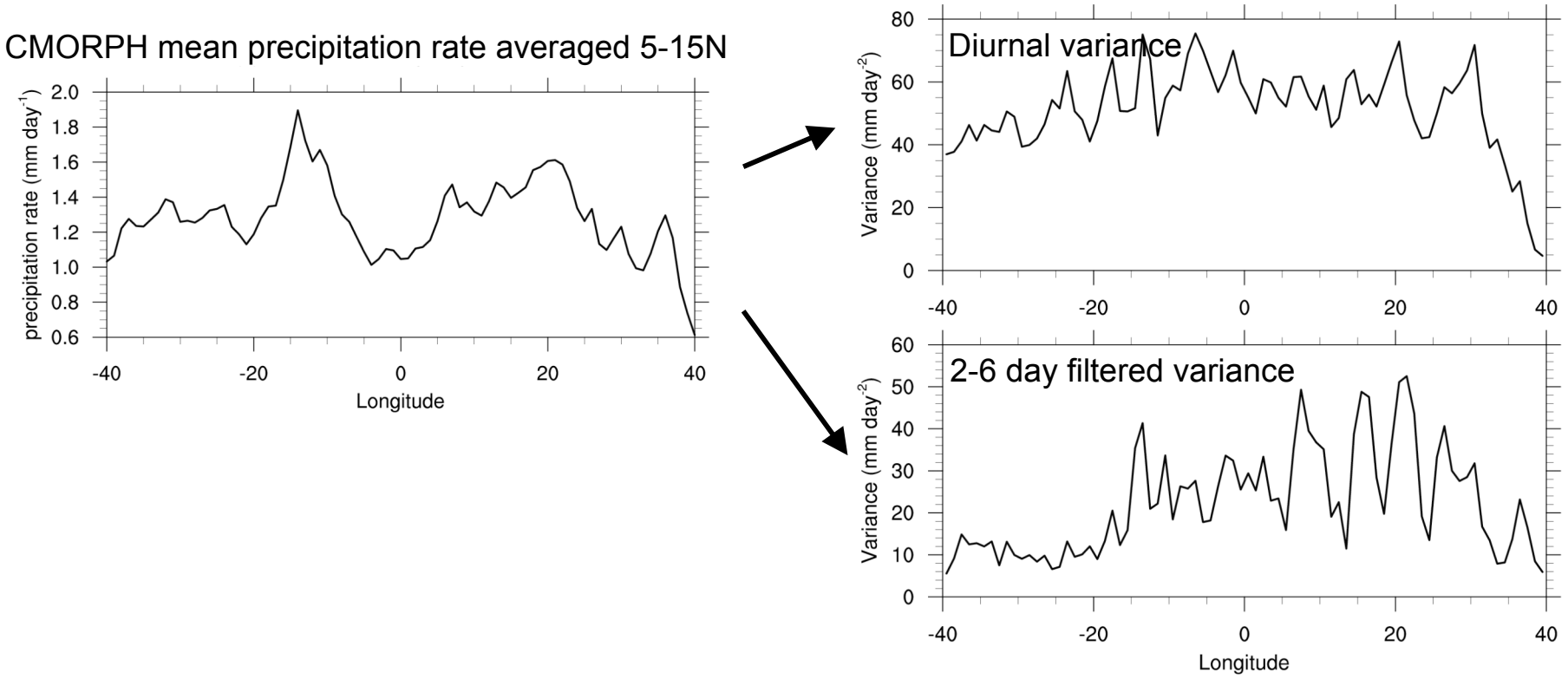


- Systematic westward drift of synoptic activity during the forecast cycle is evident in all models.
- In the ECMWF forecasts the activity initially weakens then begins to drift near day 3.
- In the UKMO forecasts there is almost no synoptic activity left over Africa by day 5.
- The synoptic activity propagates westwards at 10-15m/s.

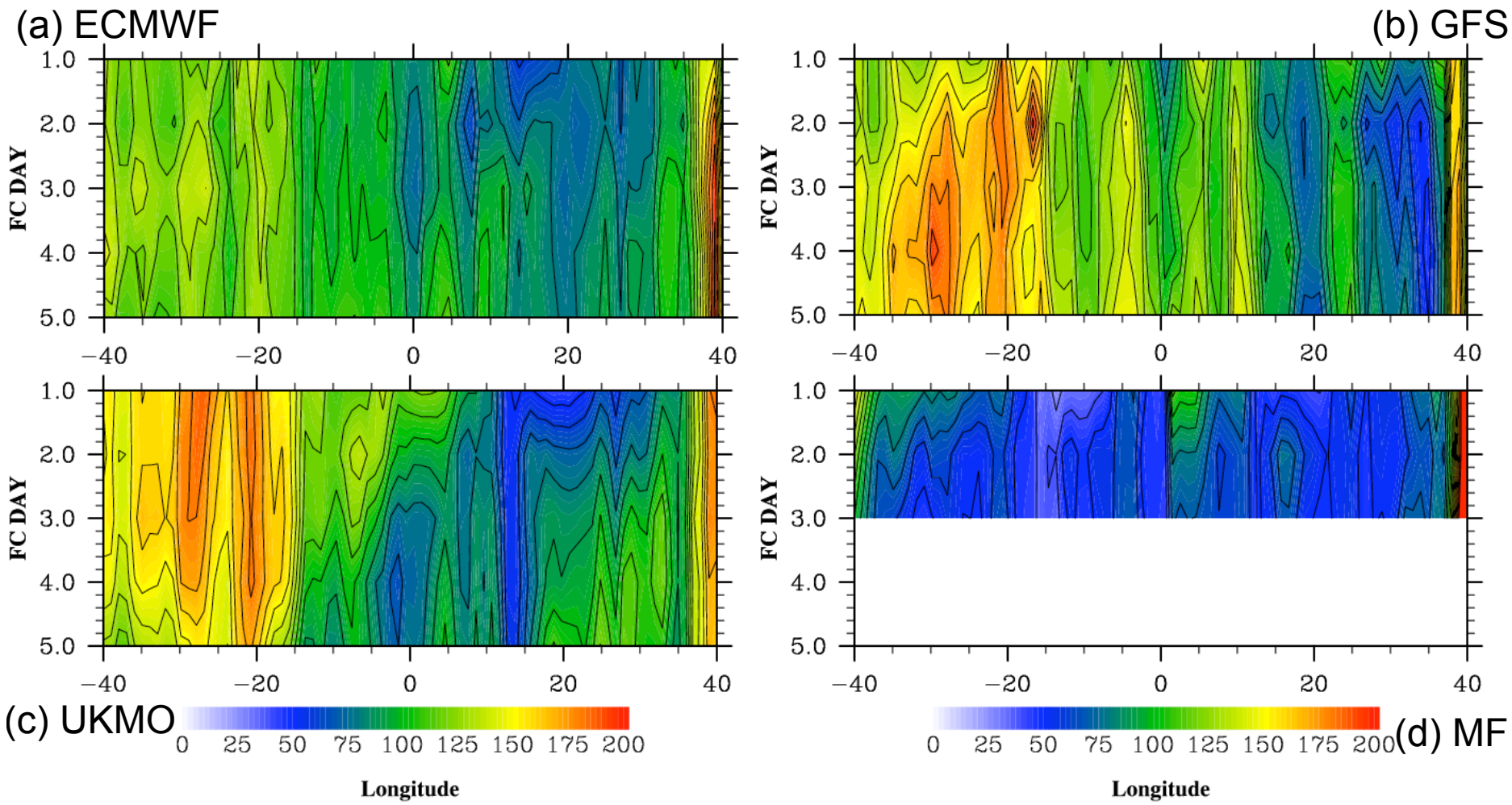
Forecast products – Systematic drift of the precipitation field.

• As noted previously the CMORPH precipitation estimate is used for verification of the model precipitation.

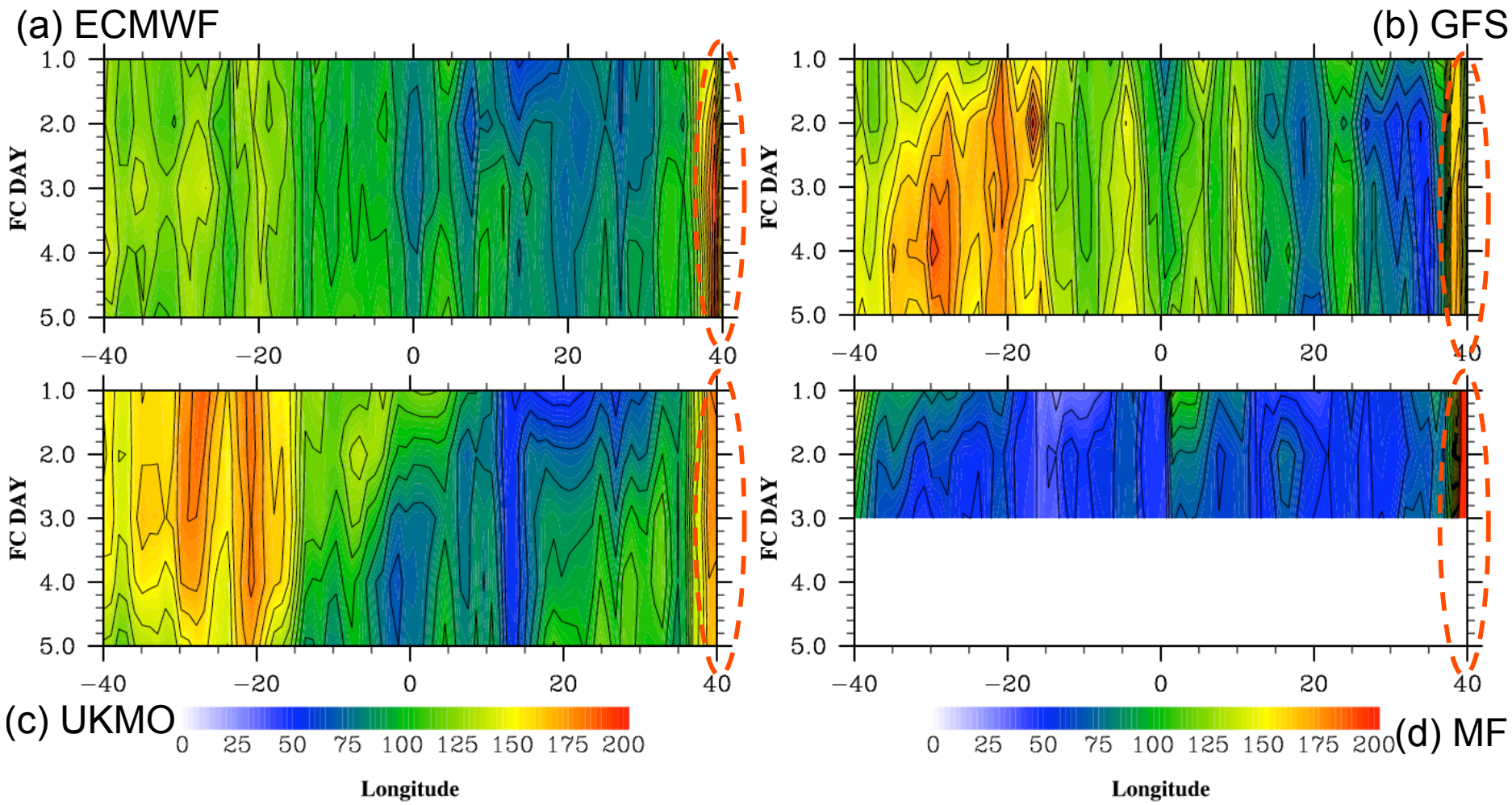
• The approach is similar to that used looking at systematic drift of the curvature vorticity field, except precipitation is subdivided into different timescales and the model precipitation is scaled relative to the CMORPH estimate.



Forecast products – Systematic drift of the mean precipitation field.

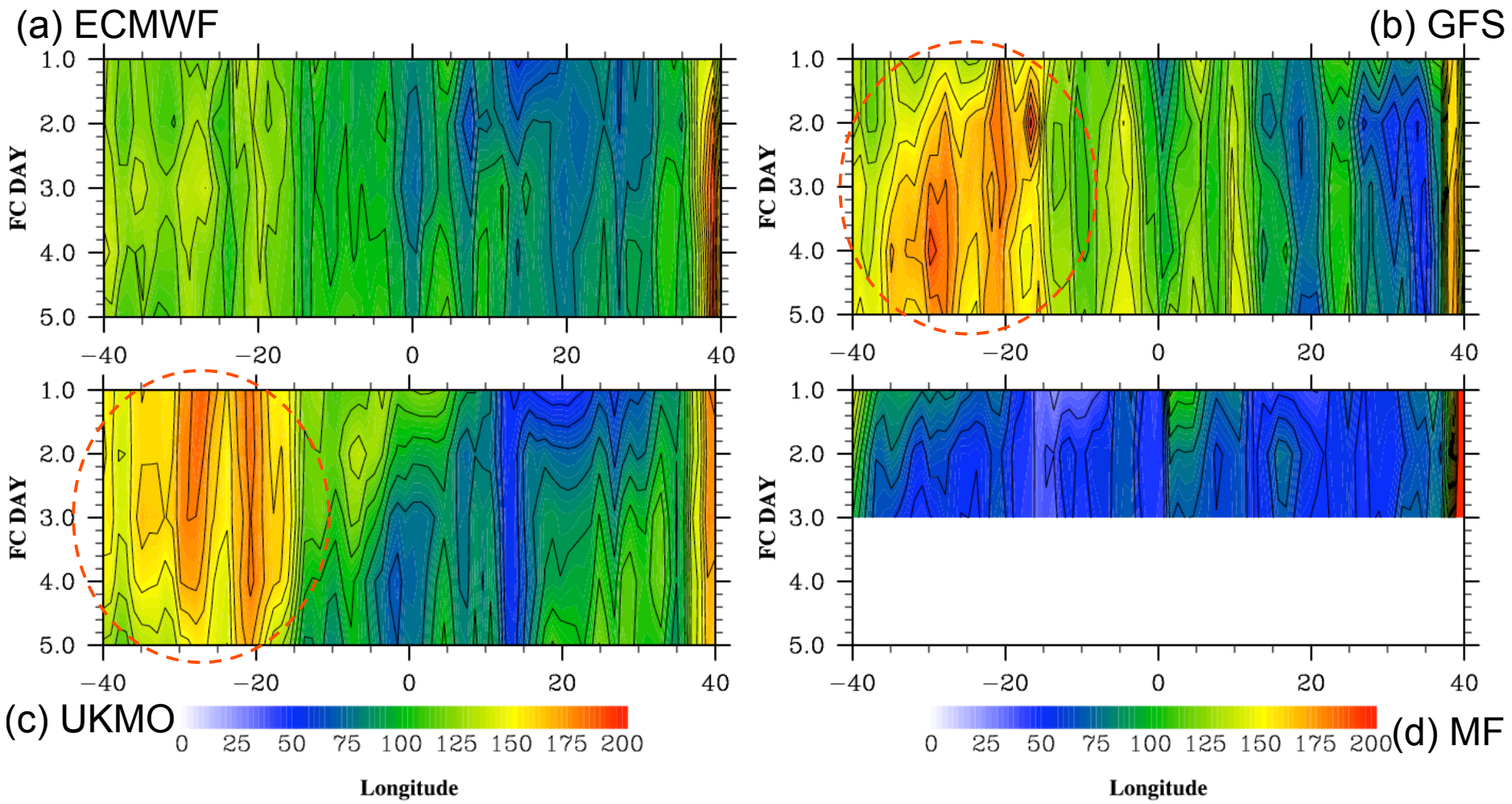


Forecast products – Systematic drift of the mean precipitation field.



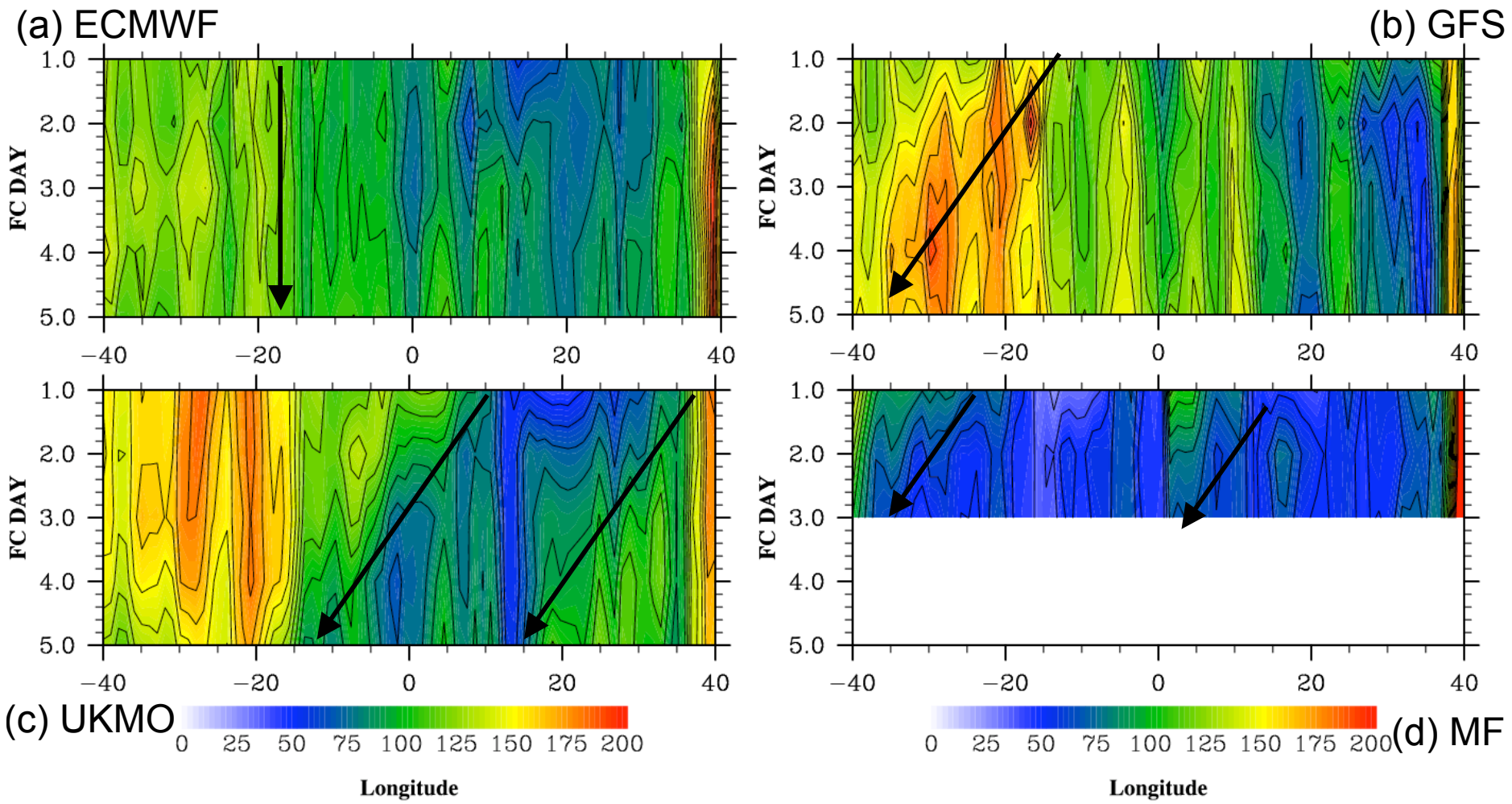
- In all, precipitation amounts are reasonable, but all overestimate in the extreme east.

Forecast products – Systematic drift of the mean precipitation field.



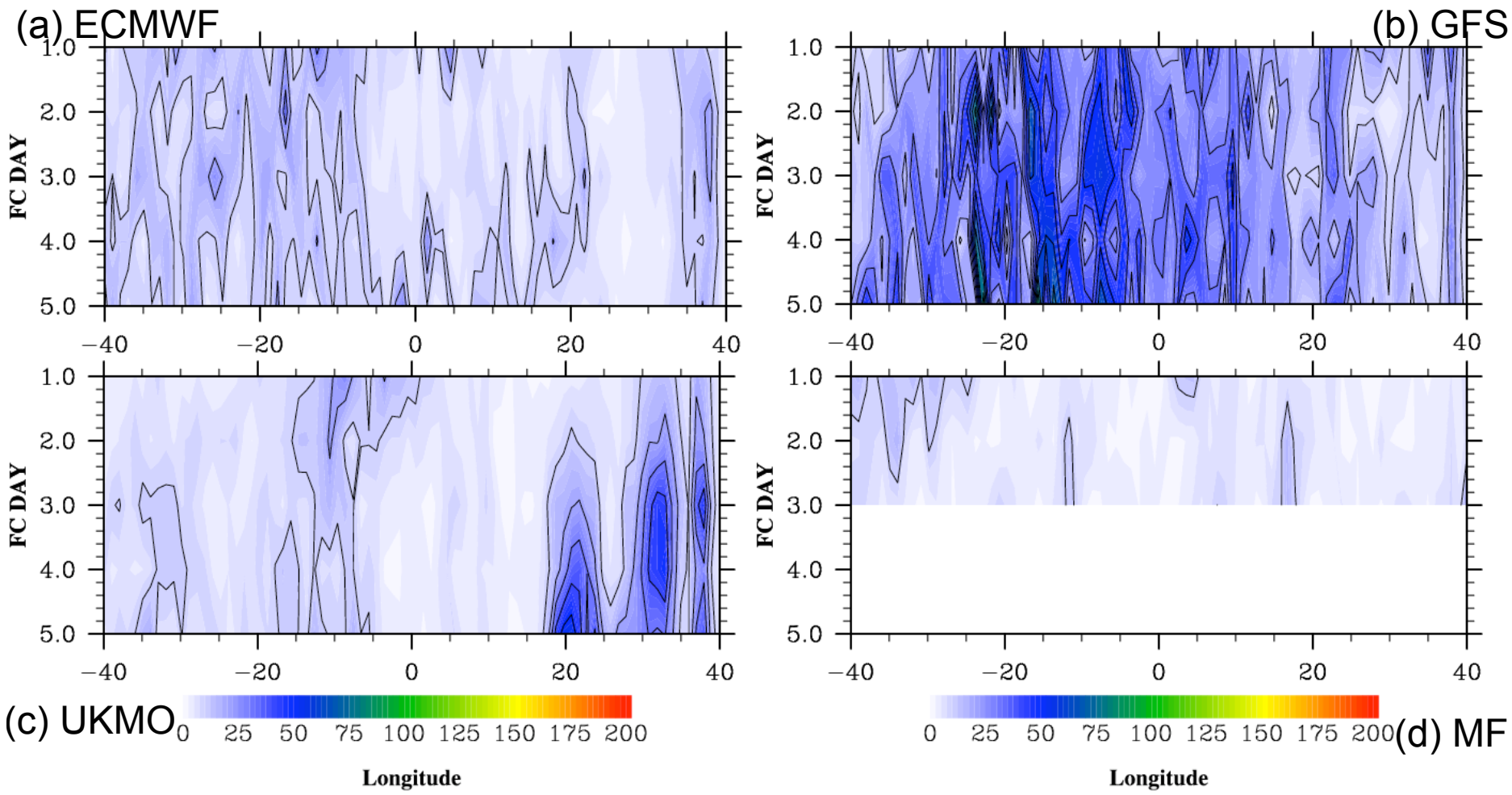
- In all, precipitation amounts are reasonable, but all overestimate in the extreme east.
- GFS and UKMO significantly overestimate precipitation off the west African coast.

Forecast products – Systematic drift of the mean precipitation field.

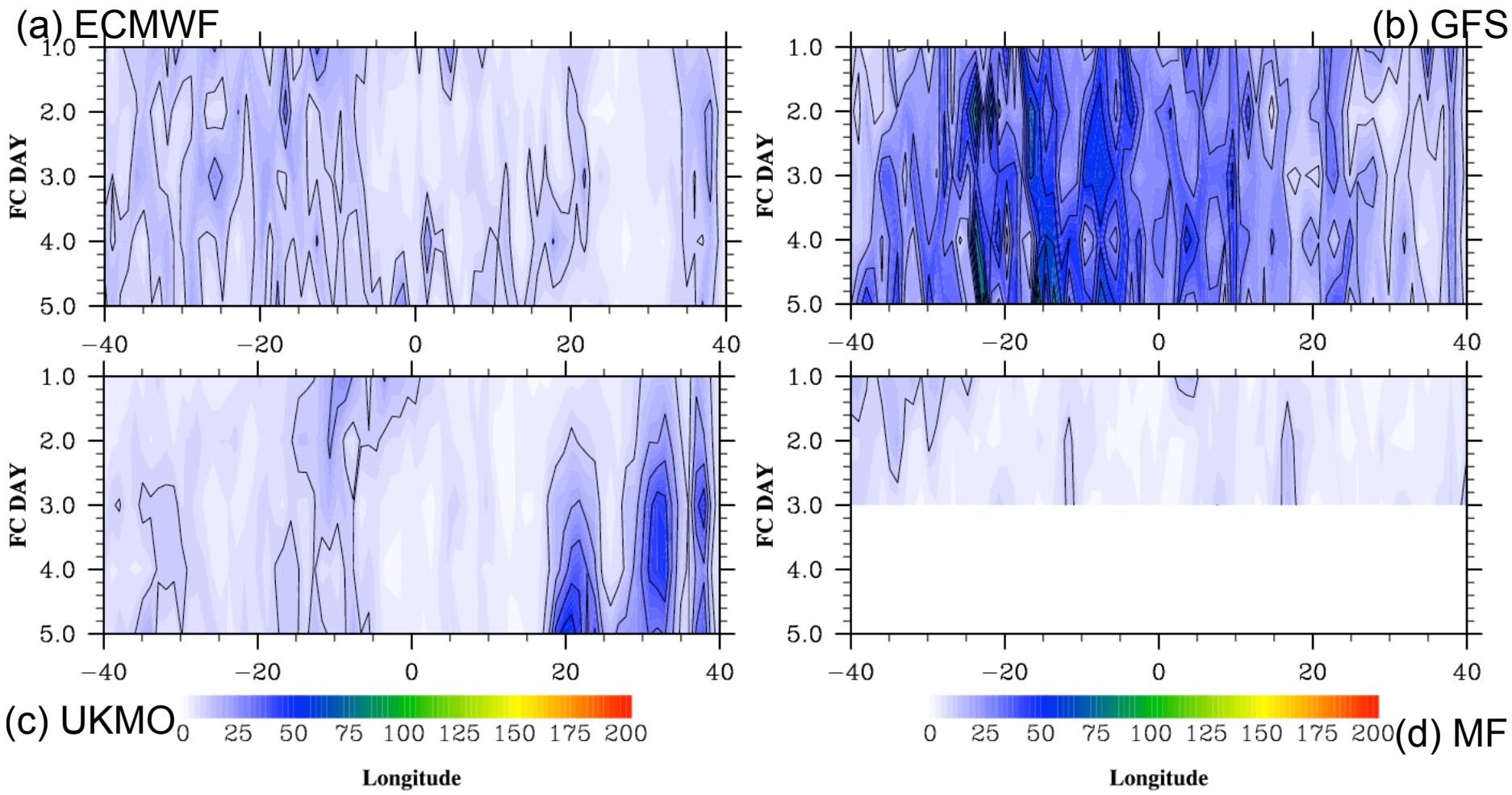


- In all, precipitation amounts are reasonable, but all overestimate in the extreme east.
- GFS and UKMO significantly overestimate precipitation off the west African coast.
- In ECMWF the precipitation rate remains steady, the other models have westwards propagating tendencies.

Forecast products – Systematic drift of the diurnal varying precipitation field.

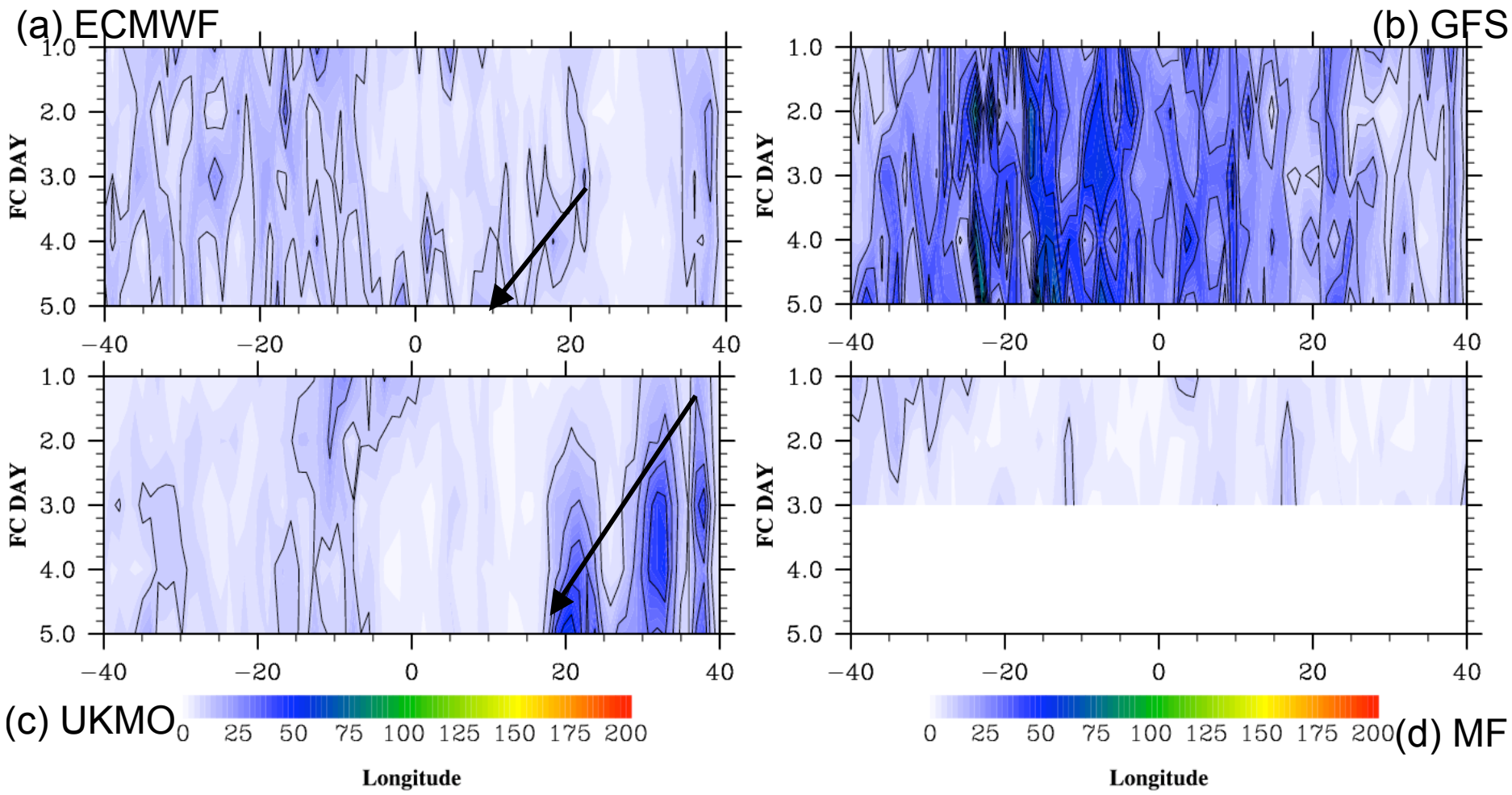


Forecast products – Systematic drift of the diurnal varying precipitation field.



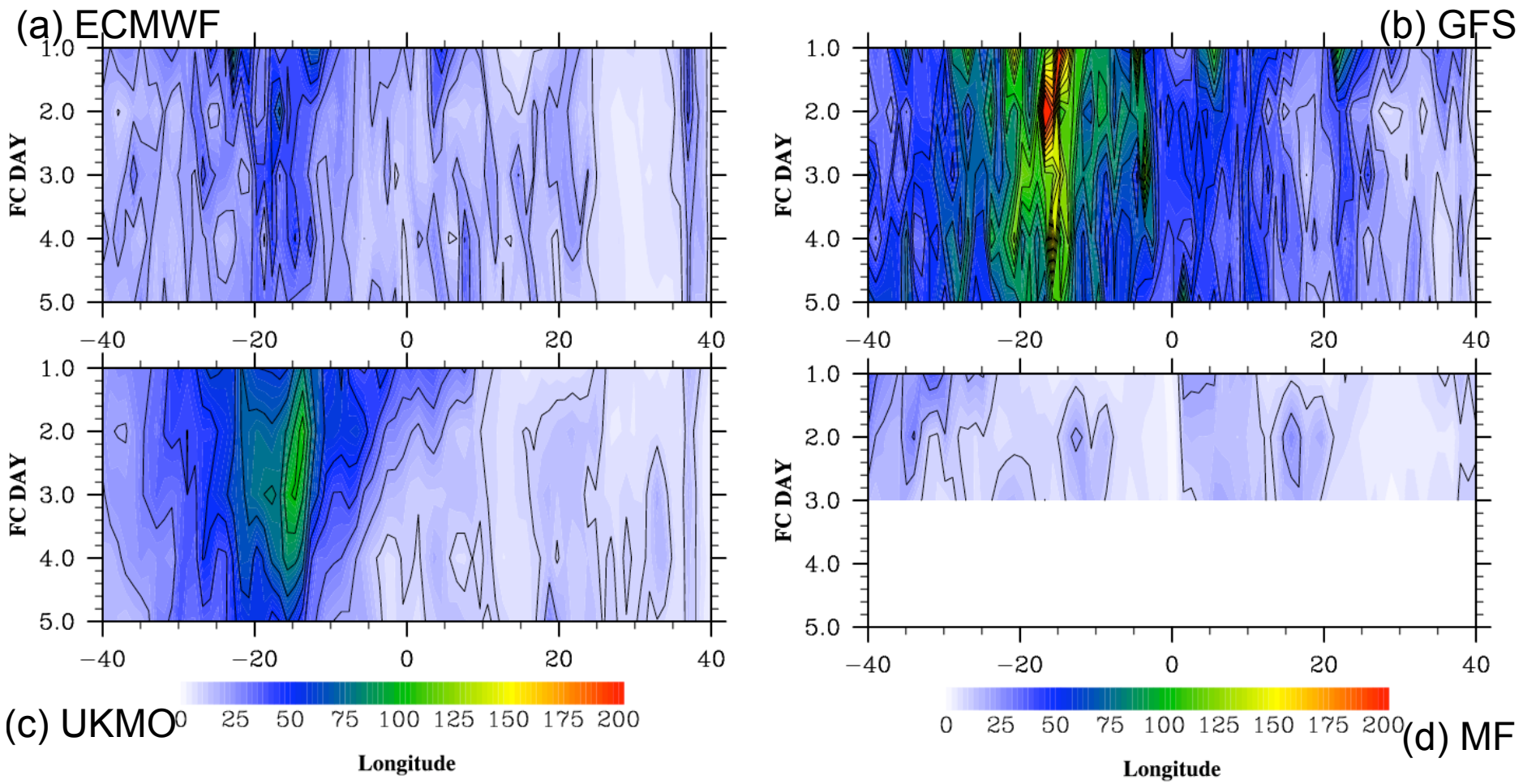
• All underestimate the diurnal variance of precipitation with respect to CMORPH throughout the forecast cycle and across the entire domain.

Forecast products – Systematic drift of the diurnal varying precipitation field.

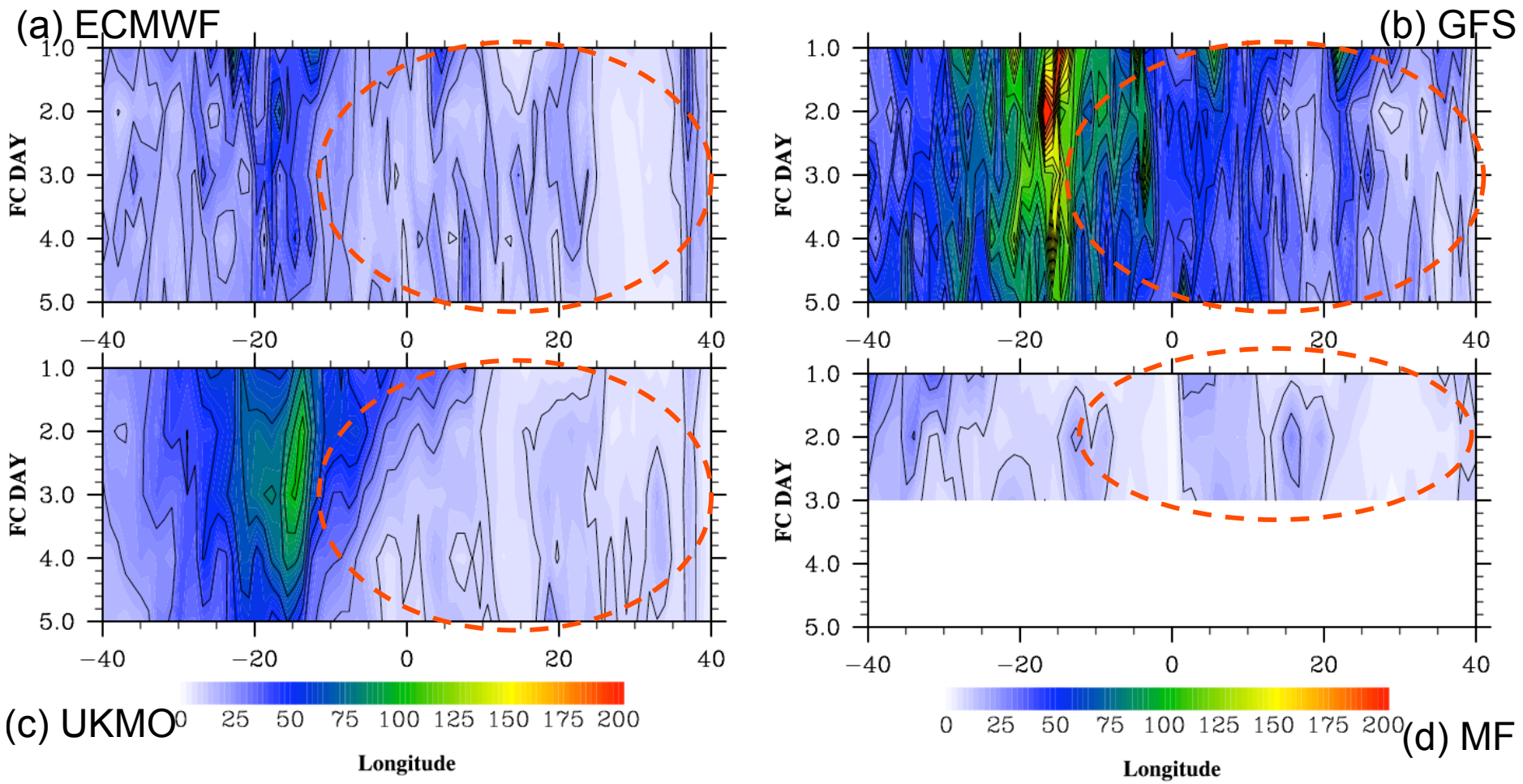


- All underestimate the diurnal variance of precipitation with respect to CMORPH throughout the forecast cycle and across the entire domain.
- The ECMWF and UKMO models show some indication of westwards drift.

Forecast products – Systematic drift of the 2-6 day varying precipitation field.

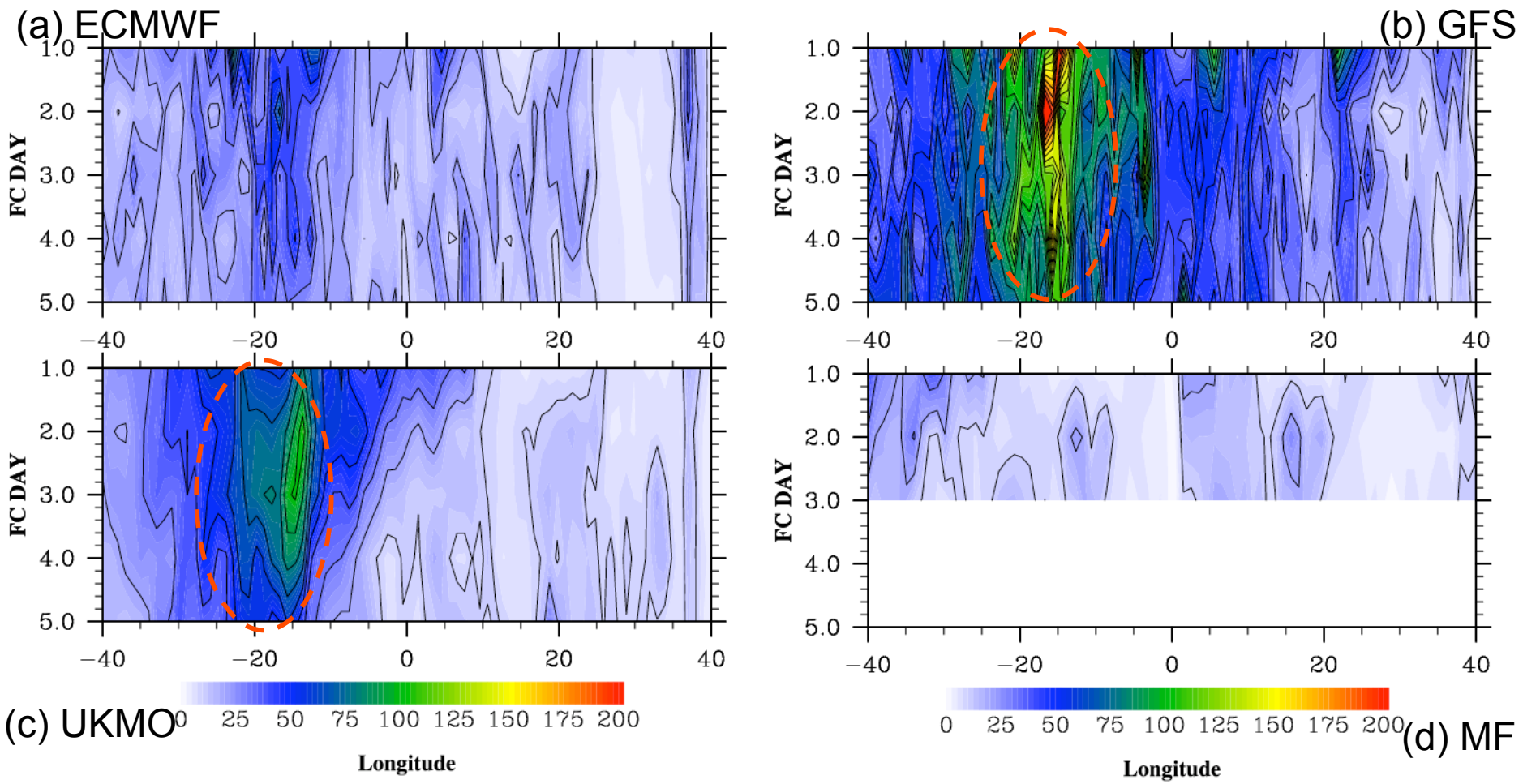


Forecast products – Systematic drift of the 2-6 day varying precipitation field.



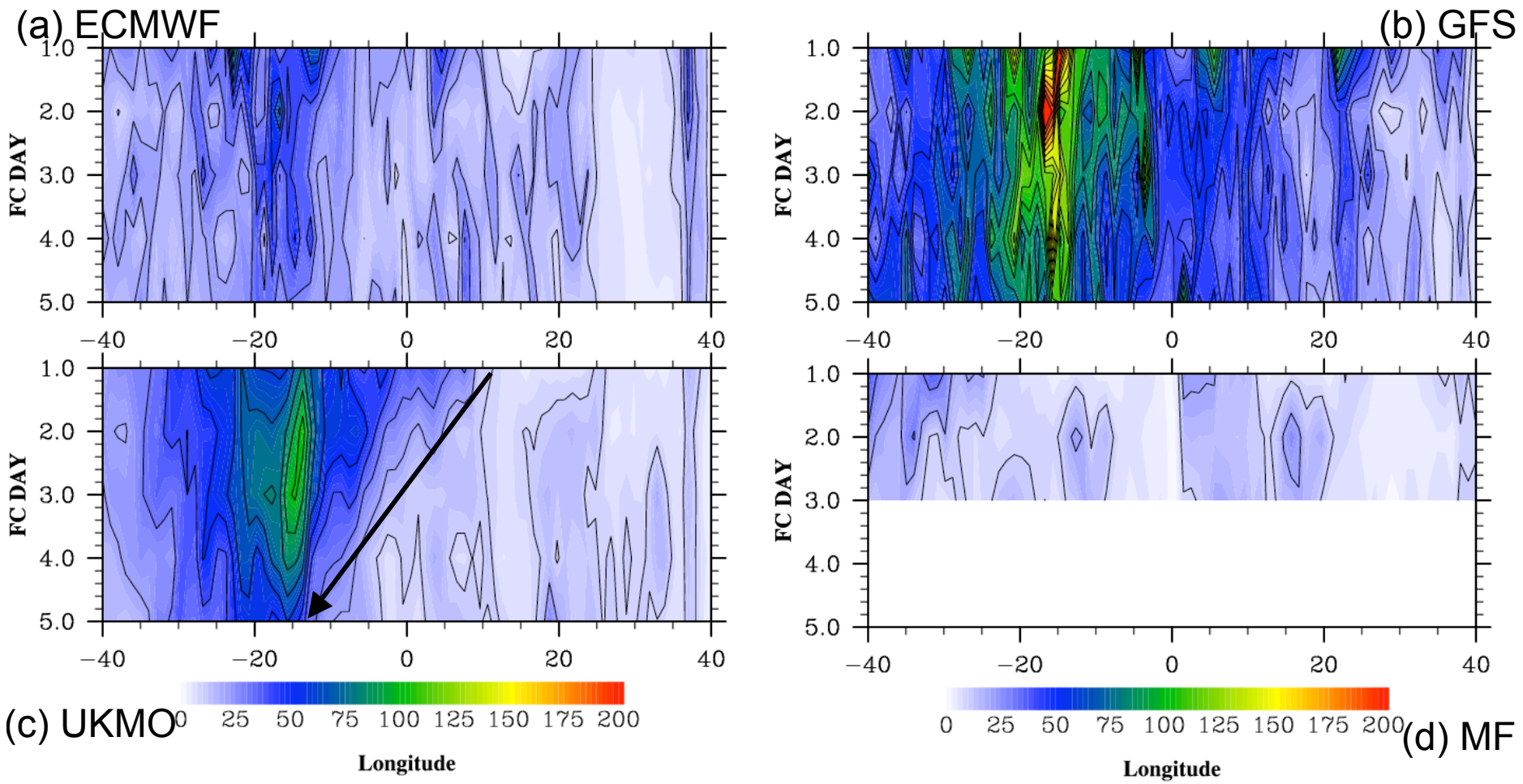
- All models tend to underestimate synoptic precipitation over the continent.

Forecast products – Systematic drift of the 2-6 day varying precipitation field.



- All models tend to underestimate synoptic precipitation over the continent.
- Only the GFS and UKMO have variance close to that of CMORPH near the coast.

Forecast products – Systematic drift of the 2-6 day varying precipitation field.



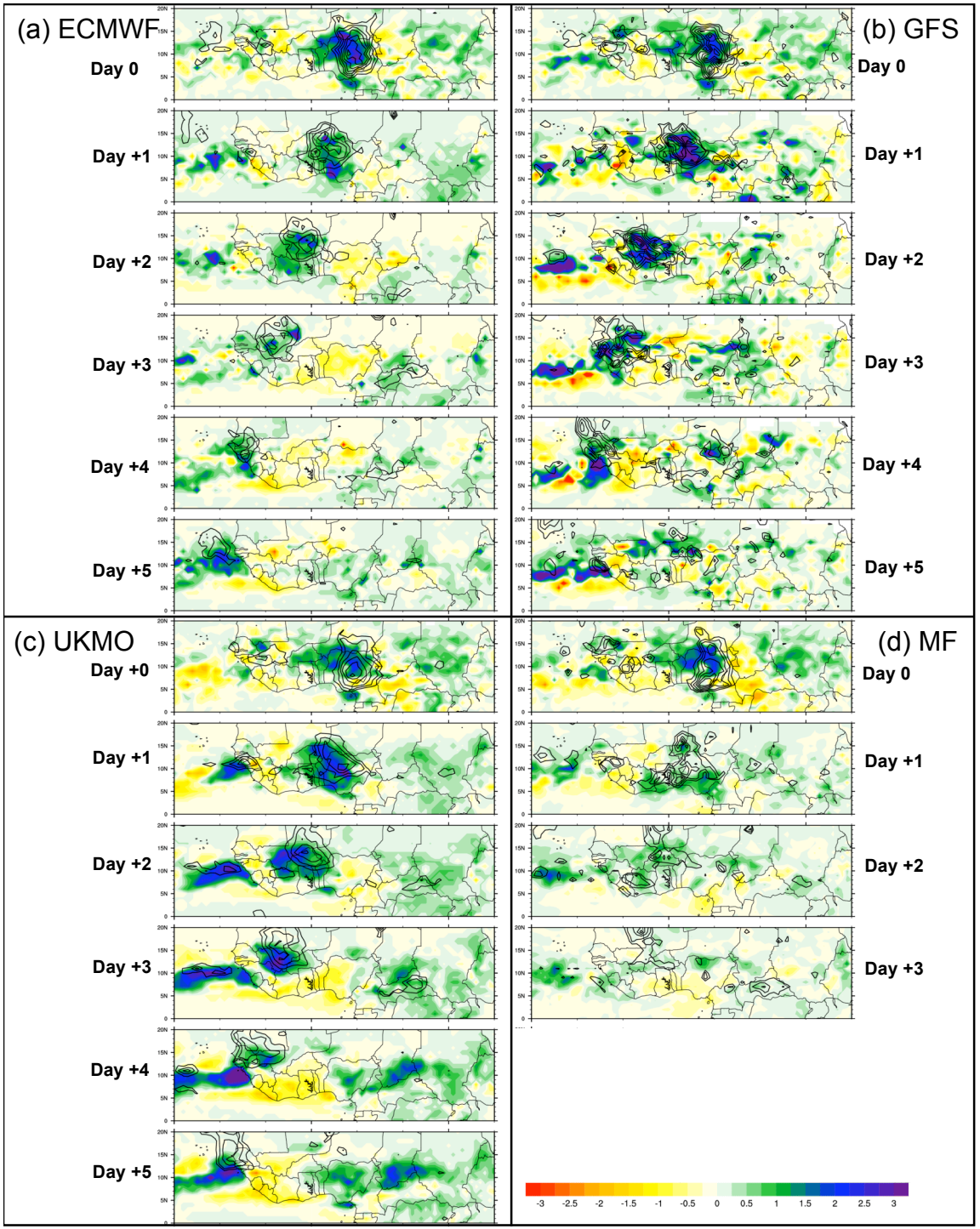
- All models tend to underestimate synoptic precipitation over the continent.
- Only the GFS and UKMO have variance close to that of CMORPH near the coast.
- Longitudinal drift still evident, especially in the UKMO forecasts.

Mean evolution of AEWs and precipitation in the forecasts.

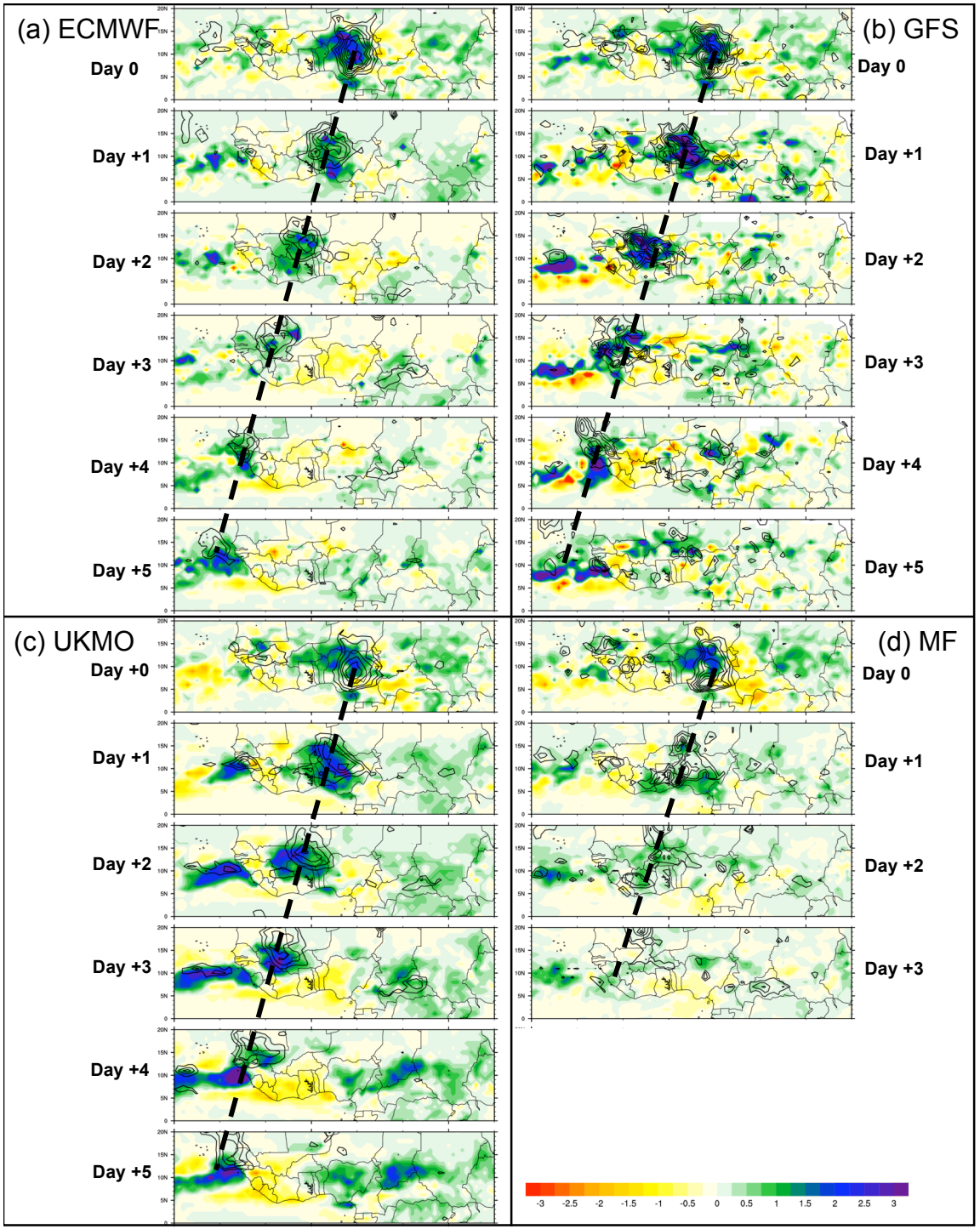
• The same lag regression techniques, based on Kiladis et al (2006) are employed in the same manner used previously in the composite analyses.

• Again, the base time series chosen is the mean 700hPa curvature vorticity 5-15N, 7.5E-12.5E, which is 4-5 days upstream of the West African coast.

• Instead of using lagged data, the forecast field are used for the regressions to generate a ‘composite forecast’.

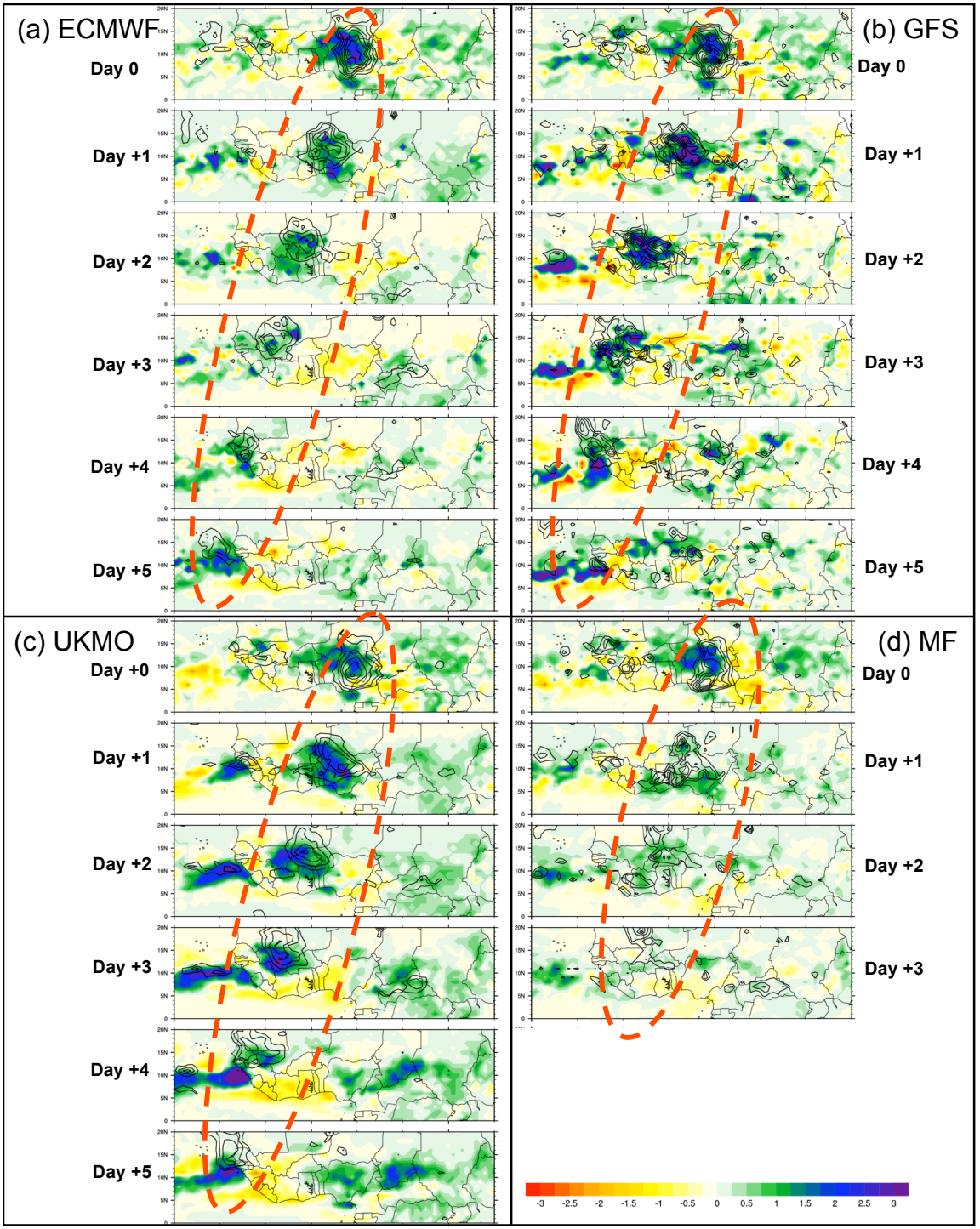


Composite evolution of forecast precipitation (colours) and 700hPa curvature vorticity (positive values contoured). Base time series: Analysis 700hPa curvature vorticity averaged 5-15N, 7.5-12.5E).



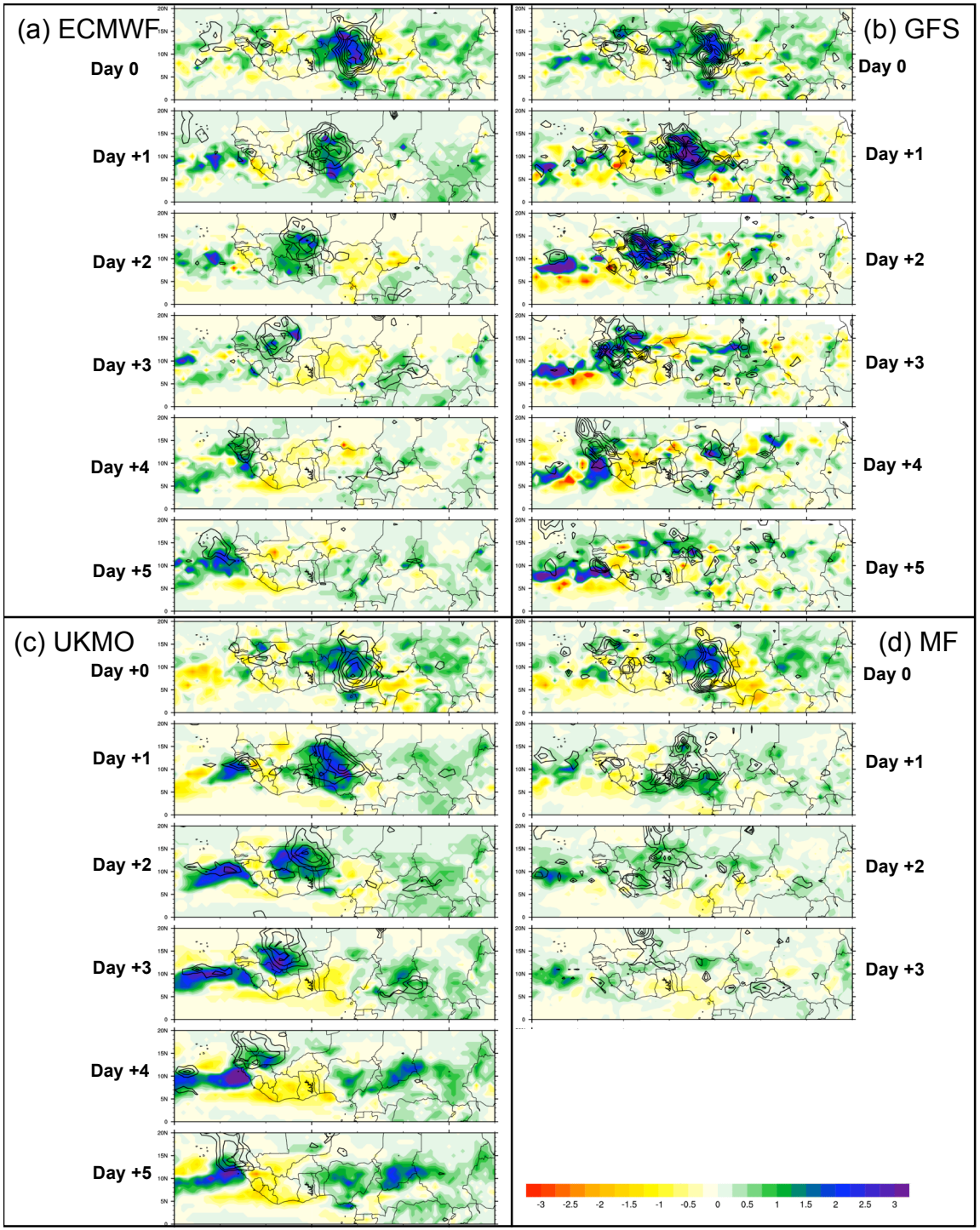
Composite evolution of forecast precipitation (colours) and 700hPa curvature vorticity (positive values contoured). Base time series: Analysis 700hPa curvature vorticity averaged 5-15N, 7.5-12.5E).

- AEW has the same phase speed in all.



Composite evolution of forecast precipitation (colours) and 700hPa curvature vorticity (positive values contoured). Base time series: Analysis 700hPa curvature vorticity averaged 5-15N, 7.5-12.5E).

- AEW has the same phase speed in all.
- Curvature vorticity maximum is much greater than in the composite analysis. – narrower range of phase speeds?



Composite evolution of forecast precipitation (colours) and 700hPa curvature vorticity (positive values contoured). Base time series: Analysis 700hPa curvature vorticity averaged 5-15N, 7.5-12.5E).

- AEW has the same phase speed in all.
- Curvature vorticity maximum is much greater than in the composite analysis. – narrower range of phase speeds?
- The curvature vorticity maximum and precipitation are co-located – the models do not represent the phase relationship correctly.

Summary and conclusions: Analyses.

• There is excellent inter-model agreement in the timing of analyzed AEWs.

• The largest differences exist in eastern Africa – AEWs are small amplitude and there is a lack of observations.

• Time series of 700hPa curvature vorticity are well correlated in the ECMWF, UKMO and MF analyses.

• Correlations are low with the GFS as a result of greater curvature vorticity variance.

• Comparison with radiosonde observations suggest this is likely due to the 2D structure of the wind field.

• Lagged correlations of the curvature vorticity and CMORPH precipitation estimates shows the model analyses can capture the subtle phase relationship between the two.

Summary and conclusions: Forecasts.

- The correlation coefficients of box averaged curvature vorticity times series are all below 0.5 after day two.

- The highest forecast correlation coefficients exist in the east, where AEW amplitudes are small and there are a lack of observations: Persistence or skill?

- The forecast precipitation fields have the correct total amounts, but this occurs on then wrong timescales.

- None of the forecast models can correctly capture the phase relationship between the AEWs and precipitation.

- All models have some degree of difficulty generating new AEWs.

- There is a tendency for the synoptic activity to propagate downstream with the speed of the mean flow.

Future work.

• Identify the reasons for the observed drift and errors in precipitation in all the model forecasts: Model physics? Lack of observations?

• Bring the objective AEW diagnostics in operational use as a readily available field or as a verification metric.

• Further develop and test the diagnostics for other applications (e.g. tropical pacific. Mid latitudes etc.).